LOW TEMPERATURE CARBONIZATION OF NON-CAKING COALS & LIGNITES AND BRIQUETTING OF COAL FINES

SYMPOSIUM
VOL. I

COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH, NEW DELHI

L.T.C. Vol. I

The industrial application of low temperature carbonization (l.t.c.) of coal has been restricted to only a few countries to meet special needs although the concept of l.t.c. is more than a century old. In India, with large resources of weakly caking coals and limited resources of good quality caking coals which have to be reserved for essentially metallurgical purposes, there is urgent need for the establishment of large scale l.t.c. briquetting and gasification plants at different coalfields. Realizing this need, two pilot plants have been in operation: one since 1954 at the Regional Research Laboratory, Hyderabad, and the other since 1961 at the Central Fuel Research Institute, Jealgora.

The Regional Research Laboratory, Hyderabad, organized a symposium on low temperature carbonization of coal during November 20-22, 1961 in order to take stock of the results of the pilot plants and plan the future programme of investigations. A wide cross-section of research scientists, coal technologists and industrialists and representatives from several leading coal processing firms in U.K., West Germany, and Japan took part in the deliberations.

The papers contributed to the symposium covering the main heads: Briquetting of non-caking coal fines and low temperature carbonization along with the discussions held during the symposium have been brought together in this present volume to be followed by a second volume containing papers and discussion on utilization of products of low temperature carbonization and survey, economics & statistics of l.t.c. products.

The publication will be of interest to all those interested in the progress of research and development of the low temperature carbonization and briquetting industry in the country.

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LOW TEMPERATURE CARBONIZATION OF NON-CAKING COALS & LIGNITES AND BRIQUETTING OF COAL FINES

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The Regional Research Laboratory, Hyderabad
November 20-22, 1961

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PREFACE

A symposium on 'Low Temperature Carbonization of Non-caking Coals & Lignites and Briquetting of Coal Fines' was held at the Regional Research Laboratory, Hyderabad, during November 20-22, 1961, under the sponsorship of the Council of Scientific & Industrial Research, India.

The symposium was inaugurated by Prof. M. S. Thacker, the then Director-General, Council of Scientific & Industrial Research, and Secretary, Ministry of Scientific Research and Cultural Affairs, Government of India, on November 20, 1961 at a function presided over by Shri S. B. P. Pattabhi Rama Rao, Minister for Education, Government of Andhra Pradesh and Chairman of the Executive Council of the Regional Research Laboratory.

With a view to allowing sufficient time for the delegates to study the papers beforehand and to enable fruitful discussions, the communications received for the symposium were circulated well in advance to all the participants. At the actual meetings of the symposium, no papers were read. The authors were invited to sum up briefly the salient points contained in the papers so that it was possible to provide much more time and scope for useful discussions.

The symposium was attended by a wide cross-section of research scientists, coal technologists, industrialists and government officials interested in the rational utilization of coal and development of the coal-based industry in the country. Representatives from several leading coal-processing firms from U.K. and West Germany also attended and took part in the deliberations.

The discussions on various papers presented were organized under four different sessions, each presided over by a separate chairman:

(*i*) Briquetting of Non-caking Coal Fines—Chairman: Dr M. S. Iyengar, Assistant Director, Central Fuel Research Institute, Jealgora

(*ii*) Low Temperature Carbonization of Non-caking Coals and Lignites—Chairman: Dr M. G. Krishna, Assistant Director, Regional Research Laboratory, Hyderabad

(*iii*) Products of Low Temperature Carbonization—Chairman: Dr S. K. Sircar, Chemical Engineer and Fuel Technologist, Calcutta (*iv*) Survey, Economics and Statistics of L. T. C. Products—Chairman: Shri S. K. Nargundkar, General Manager, The Singareni Collieries Company Ltd., Kothagudem.

The discussions on individual papers are published along with the papers and the general discussions are placed at the end of each section.

Our sincere thanks are due to the Publications & Information Directorate, Council of Scientific & Industrial Research, New Delhi, who have kindly agreed to undertake this publication. We are also highly thankful to Messrs Hyderabad Allwyn Metal Works Ltd., Hyderabad, Messrs Ballarpur Collieries Company, Nagpur, and Messrs Singareni Collieries Company Ltd., Hyderabad, for their kind help and co-operation during the organization of the symposium.

It is hoped that the proceedings will be of interest to all those interested in the progress of research and development of the low temperature carbonization and briquetting industry in the country.

New Delhi
January 10, 1963

S. HUSAIN ZAHEER

INTRODUCTION

After the Second World War, attempts have been made in all industrially developed countries to assess the reserves of different types of fuels and the pattern of utilization of energy. An important feature of these post-war developments in coal utilization in many countries is the shift in emphasis in favour of weakly caking, non-caking and low-grade coals and lignites with a view to conserving high grade caking coals. Until a decade ago, coal-based industries were almost entirely centred round coke ovens and gas works based on high temperature carbonization of coking coals. The situation has since changed significantly. Several new or improved processes, such as complete gasification and low temperature carbonization, which were used on a relatively small scale in a few countries prior to the war are now employed on a much larger scale to meet the demands for a variety of domestic and industrial fuels.

Advances in coal technology in foreign countries are making a forceful impact on India, which is on the threshold of rapid industrialization. The pattern of energy development and utilization in India should still be deemed primitive in view of the fact that over 65 per cent of the energy requirements are met from dried animal dung and agricultural fuels such as wood charcoal and farm-waste. Coal contributes 30%, oil 4%, and hydro-power 1% of the energy requirements. The diversion of farm-waste and dung for fuel purposes has resulted in serious loss of soil fertility and low yield of food grains. The increasing demand for firewood and charcoal has resulted in extensive denudation of forests. Afforestation not being able to keep pace with deforestation, the net effects of soil erosion, loss of soil fertility and low food grain production have become alarming. It has, therefore, become imperative that the fuel habits of the people and the pattern of consumption of energy in India undergo a drastic change in favour of fossil fuels. Granting that about 75 per cent of the Indian population who are engaged in agriculture will continue to use firewood and charcoal for several years to come, and assuming that all the animal dung and farm-waste will be used as manure, it is expected that, by 1965, about 51 per cent of the energy requirements would be met from coal, 9 per cent from oil and 35 per cent from agricultural sources. The present trend shows that this would not be achieved and the proportion of agricultural fuels would be much higher.

At present fuel for domestic use comprises mostly of firewood, charcoal and dried dung (equivalent to about 95 million tons of coal) and about 2-3 million tons per annum of coal and coke. To bring about a change-over in the energy pattern, reactive, smokeless solid fuels derived from coal and fuel gas from coal or oil have to be made available as substitutes. This can largely be achieved by low temperature carbonization of about 10-20 million tons of non-caking and weakly caking coals and lignites within the next ten years, expanding ultimately to about 40-50 million tons per annum. Part of the domestic demand can also be met by fuel gas made by complete gasification of coal.

The increased mechanization of coal mining envisaged during the Five Year Plan periods also would simultaneously lead to production of 15-20 per cent of coal slacks below 0·5 in. size. Although most of the slacks will be utilized in the proposed high capacity thermal stations, substantial quantities are expected to be available for production of coal briquettes. The handling and storage of low rank coal fines and lignites present many problems due to their susceptibility to spontaneous combustion and disintegration on storage. One solution is to briquette them with or without a binder into shaped fuels which can easily be handled and used for subsequent carbonization to produce lumpy domestic fuel.

There is thus an urgent need for the establishment of large-scale low temperature carbonization (l.t.c.), briquetting and gasification plants at the different coalfields of India to process non-caking, weakly caking and low-grade coals and lignites. However, there is as yet not a single large-scale l.t.c. plant in India. Two pilot plants are, however, in operation, one since 1954, at the Regional Research Laboratory, Hyderabad, and the other since 1961, at the Central Fuel Research Institute, Jealgora. Likewise no briquetting plants are installed at any of the Indian coal mines. The first, on a large-scale is expected to be commissioned at Neyveli during 1964-65 to produce about 800,000 tons per annum of briquettes from South Arcot lignite, using an extrusion press, which will be carbonized in an internally heated l.t.c. plant to produce 380,000 tons per annum of briquette char for use as domestic fuel. Town gas supply in long distance grid systems is also being planned, based on integration of coke ovens, gasification plants and natural gas supply.

Although the concept of l.t.c. is more than a century old, its industrial application is restricted to a few countries and even there on a relatively small scale and to meet special demands. The aims of l.t.c. are many-fold. The most important has so far been the production of lumpy, reactive, domestic fuel. Many others, such as production of powdered char for power generation and for blending with caking coal to produce hard coke, are gaining increasing importance. L.t. semicoke is found to be an excellent reductant and fuel in low shaft furnaces for production of pig iron. In some processes, l.t.c. and briquetting are two of the stages in the manufacture of hard coke from weakly caking or non-caking coals. L.t.c. is likely to gain considerable impetus in future owing to the increasing need for utilization of coals of lower rank and grade with a view to conserving the fast depleting world reserves of good caking coals. Briquetting, particularly at elevated temperatures, is showing promise for the manufacture of hard coke from non-caking coals.

Apart from the limited uses of l.t. char, the difficulties in the disposal of l.t. tar were perhaps greatly responsible for the absence of large-scale l.t.c. industry. True l.t. tar is much less aromatized than h.t. tar. It contains negligible quantities of solid aromatics such as naphthalene and anthracene and relatively small quantities of simpler aromatics like benzene, toluene and xylene. It contains 25-30 per cent of tar acids, most of which comprise of cresols, xylenols and high boiling tar acids, but very little of phenol. The difficulties in processing l.t. tar for production of readily marketable products, have, therefore, made its disposal and, very often, the whole l.t.c. industry uneconomic except under special circumstances such as war-time emergency that existed in Germany where the entire l.t. tar from lignite was hydrogenated for production of liquid fuels. On the other hand, the very complicated nature of l.t. tar demands intensive researches to understand its chemical character and new approaches for successful processing.

In India, with the large reserves of weakly caking, and non-caking coals with relatively high ash content and the limited reserves of good quality caking coals which have to be conserved for essential metallurgical purposes, preference should be given to the use of non-caking coals as much as possible. There is thus a virgin field for the development and application of new techniques to make the best use of inferior coals.

The papers presented at the symposium cover several l.t.c. processes, new techniques of briquetting and methods of recovery and processing of byproducts. The growing importance of the subject of the symposium is reflected by the large number of papers received from several countries and from institutions within India. It is hoped that the deliberations of the symposium will lead to the development of large-scale low temperature carbonization, briquetting and byproduct processing industries and that the ideas emanating from the papers and discussions will lead to further intensive researches in the respective fields.

M. G. KRISHNA

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SECTION ONE

Briquetting of Non-caking Coal Fines

Briquetting of Non-caking Coal

Y. SANADA & H. HONDA

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Japan

Compression strength of binderless briquettes is known to be low for low-rank bituminous coals and this characteristic is related with the plasticity of coals. Experiments with coal immersed in pyridine showed a decrease in microhardness value, leading to an increase in plasticity. Binderless briquetting of two Japanese coals immersed in pyridine, benzene, tar bases, liquor ammonia and aqueous caustic soda have been studied. Coals containing absorbed pyridine gave briquettes with an increase in apparent density and hardness value reaching a maximum at the optimum value of absorption. The increase in apparent density and hardness value of raw briquettes is also reflected in the briquettes carbonized at 1,000°C.

Several theories have been proposed to explain the mechanism of briquetting of coal[1,2]. Attempts have also been made for evaluating briquettability of coal based on elastic and plastic properties[3–5]. It is generally known that coals, except anthracite, can be briquetted by pressure alone without binding materials such as tar, pitch, etc. The compression strength of briquettes prepared from air-dried coal shows a minimum for coal having about 80 per cent carbon (dry ash-free basis). This characteristic is closely connected with the hardness, elasticity and plasticity of coals. The maximum indentation hardness, the maximum elasticity and the minimum plasticity are all shown for coals having about 80 per cent carbon content[6]. The present paper describes the studies undertaken to obtain a better understanding of the effect of coal plasticity on briquetting.

The authors have found that the microhardness value of coals immersed in a solvent decreases markedly with the immersion time[7]. Experimental

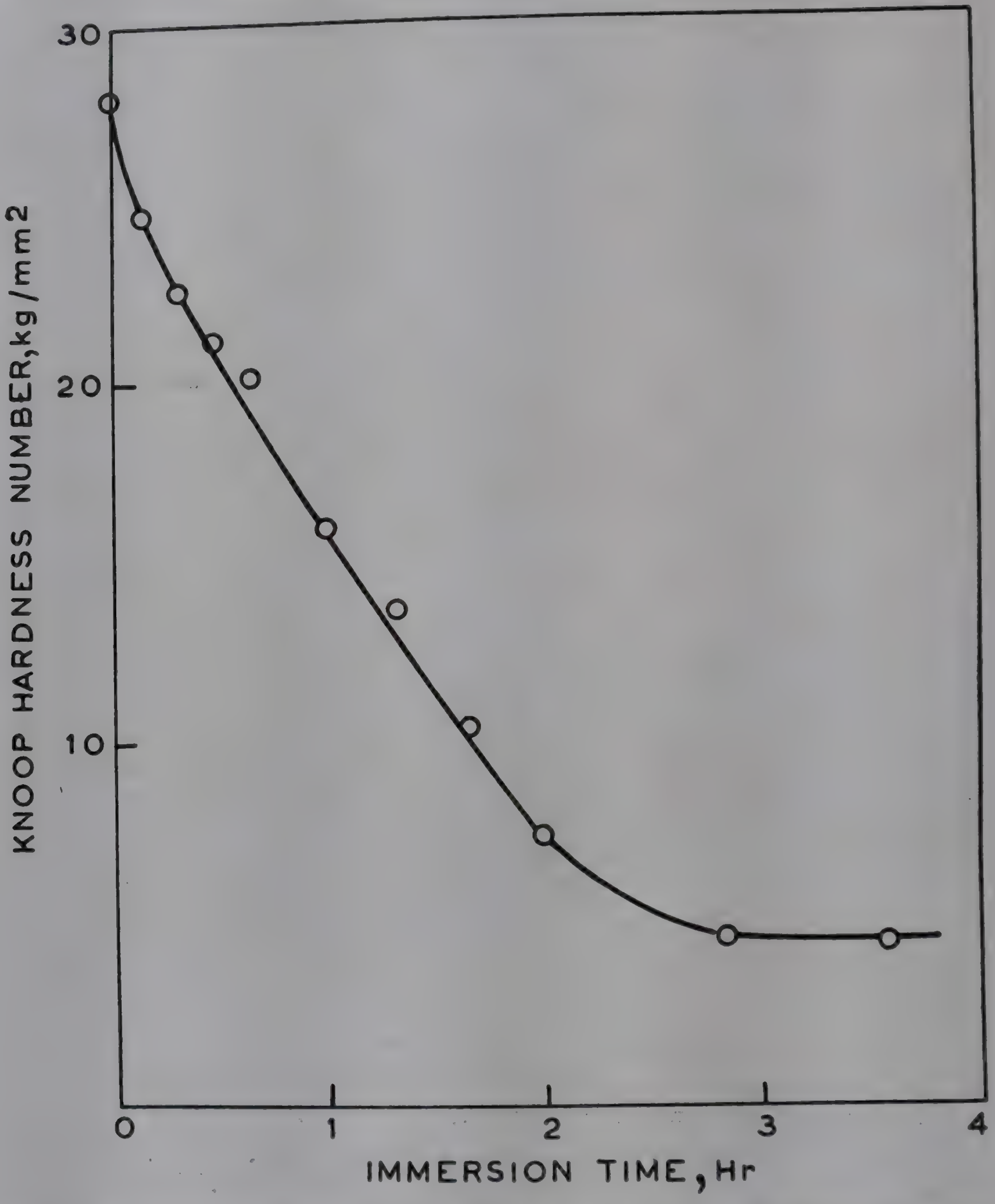

FIG. 1—VARIATION OF KNOOP HARDNESS NUMBER OF TAKAMATSU COAL IMMERSED IN PYRIDINE VS. TIME

results of Takamatsu coal immersed in pyridine are shown in Fig. 1. The H_k of Takamatsu coal is 29 kg./sq.mm. before immersion and when immersed in pyridine decreases rapidly with time. After about 3 hr it reaches an equilibrium value of 4·6 kg./sq.mm. The relation between the hardness ratio, $H_k/H_{k,o}$ (where H_k is the equilibrium Knoop hardness number of coal immersed in pyridine and $H_{k,o}$ is that of original coal) and rank of coal is shown in Fig. 2. For brown coals and non-caking coals the hardness ratio decreases with increasing rank and shows a minimum at about 80 per

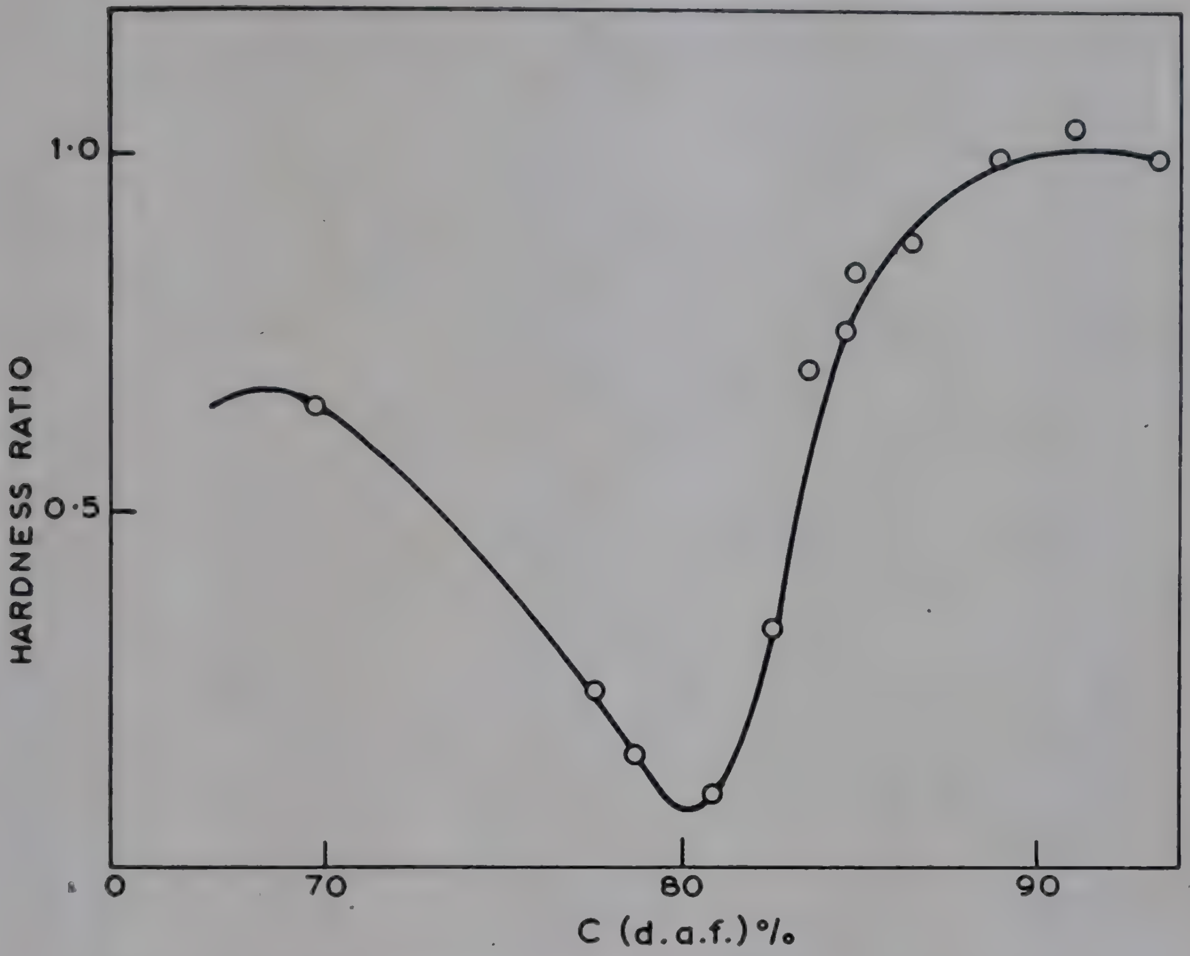

FIG. 2—RELATION BETWEEN HARDNESS RATIO $\frac{H_k}{H_{k,o}}$ AND RANK OF COAL

cent carbon content. For caking coals, the hardness ratio increases with rank. The microhardness of anthracite immersed in pyridine does not change with time. It is interesting to note that the higher the microhardness number of the original coal, the lower it ultimately becomes when immersed in pyridine, except in the case of anthracite. This indicates that the coal containing absorbed solvent leads to increased briquettability.

Binderless briquettes of Takamatsu and Bibai coals having about 80 per cent carbon (on dry ash-free basis) could be made, though they show a minimum briquettability. The characteristics and sieve analysis of the two coals are shown in Tables 1 and 2 respectively. A desired solvent absorption in air-dried samples was obtained by keeping the sample in a desiccator at room temperature. These samples were briquetted at a pressure of 1,000 kg./sq.cm. or 2,000 kg./sq.cm. Solvents used were pyridine, benzene, tar bases (a fraction at 0–200°C.), liquor ammonia and aqueous caustic soda. The briquettes made were of cylindrical shape having 2 cm. diameter, about 1·2 cm. height and 4 g. in weight. The physical properties, apparent density and Brinnel hardness value, which are proportional to compression strength, were determined[8].

The results obtained using Bibai coal are presented in Table 3. Similar

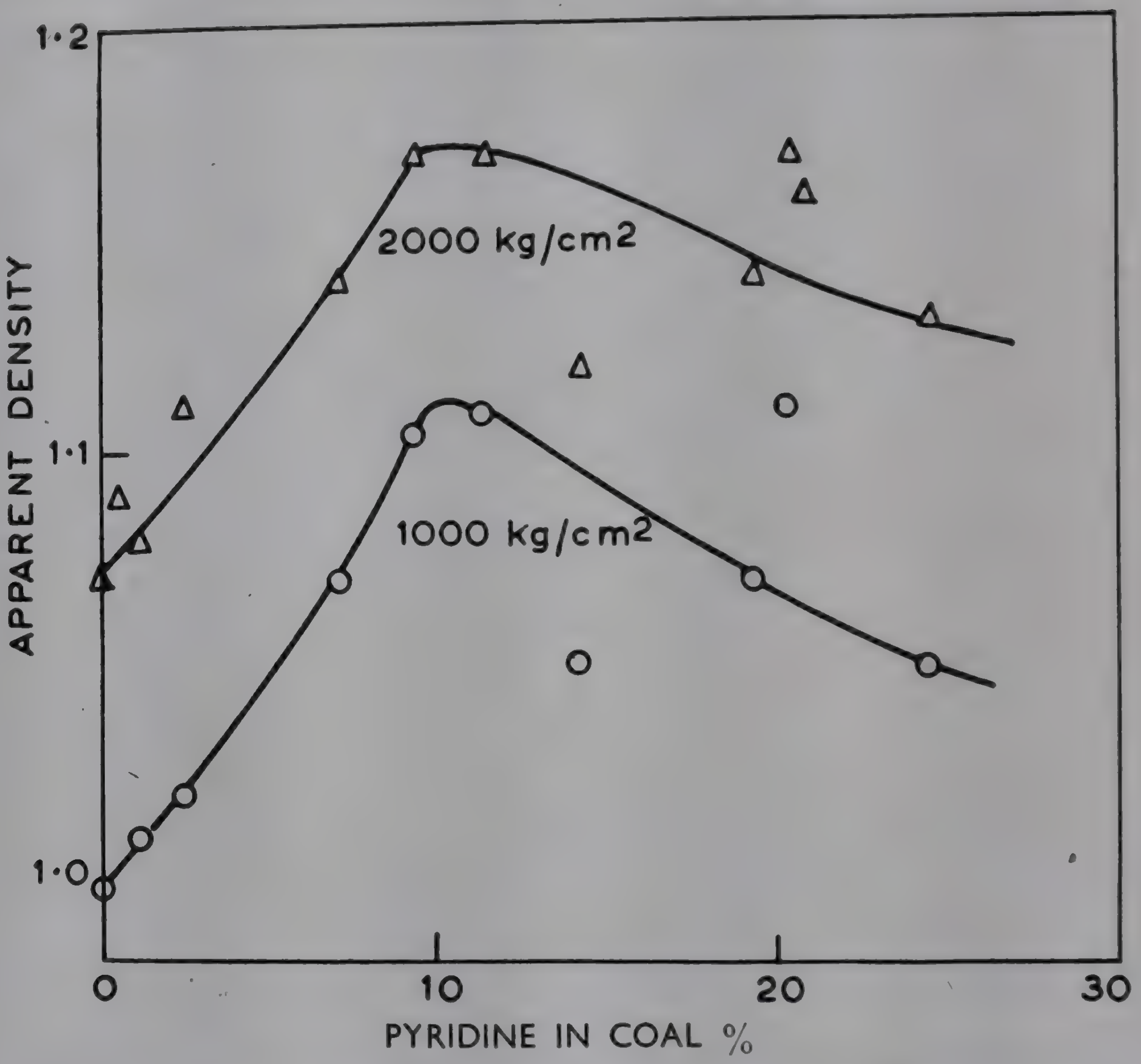

FIG. 3—INFLUENCE OF PYRIDINE CONTENT ON THE BRIQUETTING OF TAKAMATSU COAL

results were also obtained with Takamatsu coal. These results show that the polar liquids (basic solvents such as pyridine, tar bases) increase the apparent density and hardness value of briquettes. On the other hand, the apparent density and hardness value of briquettes using nonpolar liquids (benzene), and inorganic basic liquids (ammonia liquor and aqueous caustic soda) are of the same order as those obtained with air-dried samples. Figs. 3 and 3A show the variation of the apparent density and Brinnel hardness value of Takamatsu briquettes against pyridine content. Basic liquids exhibit a maximum apparent density and hardness value at an optimum concentration in a similar manner to moisture in lignite briquettes. Increase of briquettability mentioned above is due to the decrease of hardness value, that is, increase of plasticity as reported in lignite briquettes[4]. If the hydrogen bondings through the hydroxyl or carboxyl radicals of contiguous units in coal, i.e. acid sites, are released by a basic liquid, the inorganic basic solvents such as ammonia liquor, etc. must also be effective. But this assumption is contrary to the above findings.

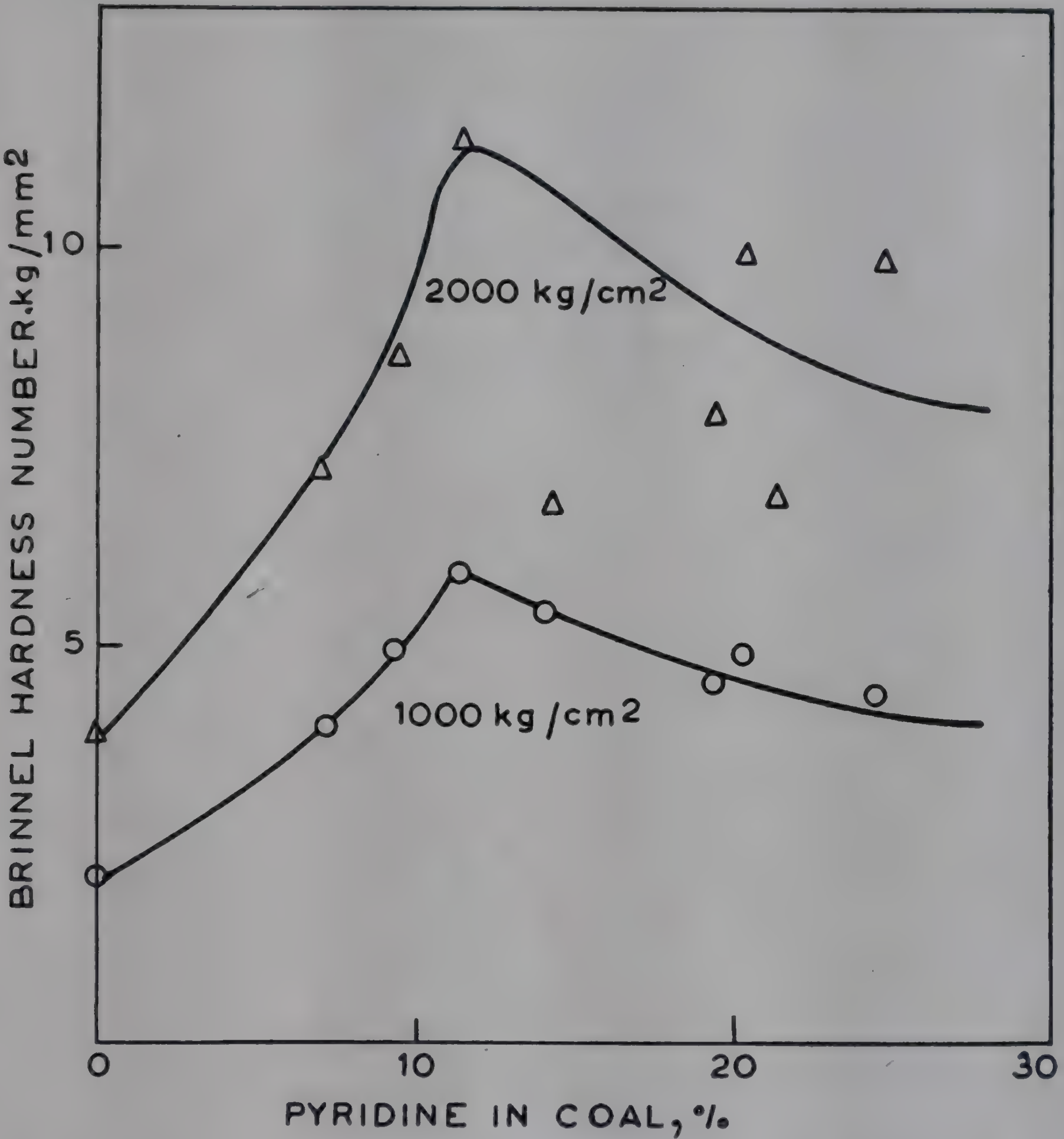

FIG. 3A—INFLUENCE OF PYRIDINE CONTENT ON THE BRIQUETTING OF TAKAMATSU COAL

The briquettes were carbonized at 1,000°C. with a heating rate of 2°C./min. and total heating time of 8-9 hr. Apparent density and Shore rebound hardness value of carbonized briquettes are shown in Table 3. Figs. 4 and 4A show the relation between the apparent density and Shore hardness value of carbonized Takamatsu briquettes and the pyridine content in raw briquettes. It will be noted that the increase of the apparent density and hardness value of raw briquettes resulted in increased values for briquettes carbonized at 1,000°C.

These results demonstrate conclusively that briquettability of coal is largely due to the degree of plasticity present in coal. While a quantitative interpretation of the above results will have to await further confirmation, it appears that the increase of briquettability of non-caking coal is caused

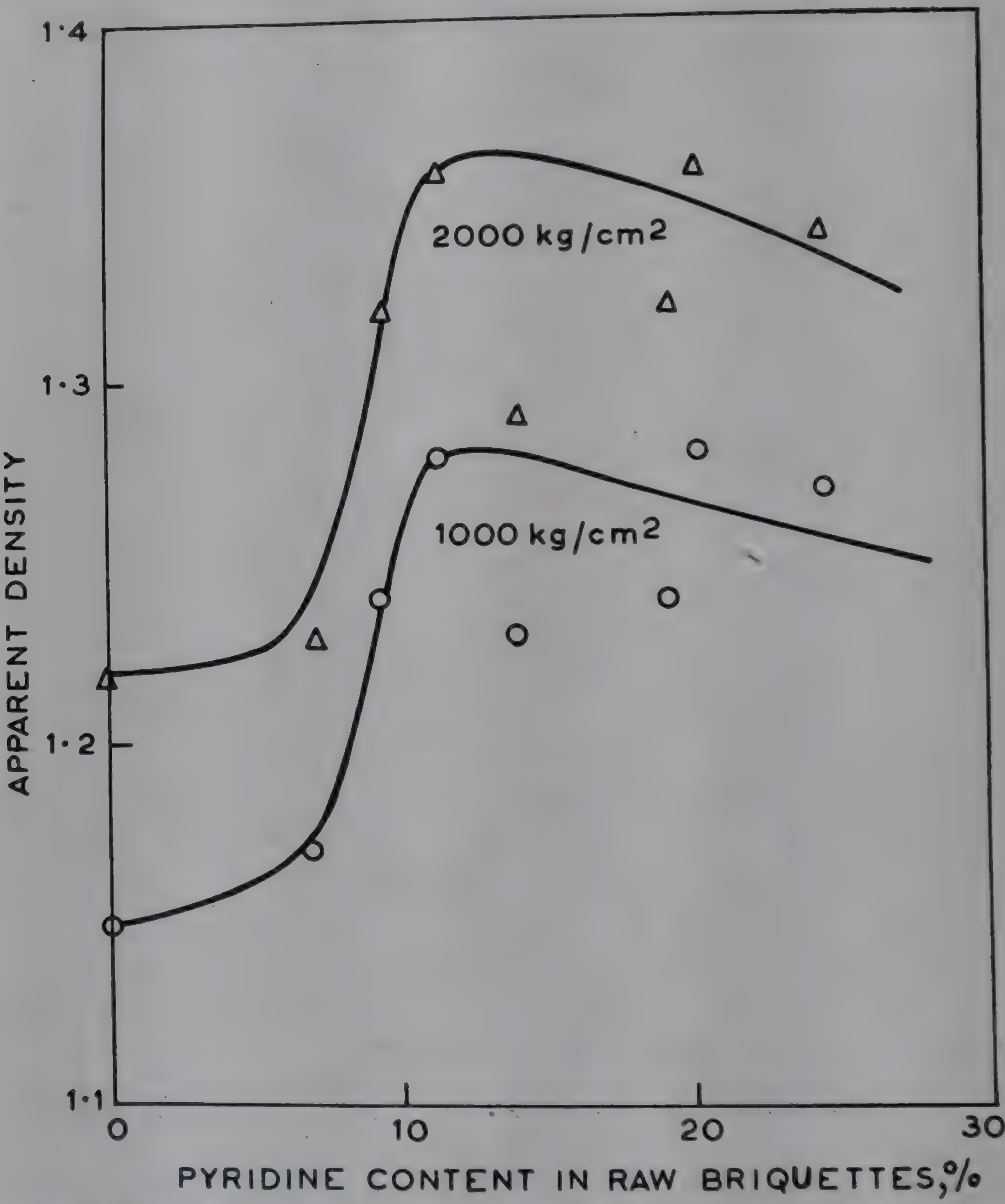

FIG. 4—RELATION BETWEEN APPARENT DENSITY OF TAKAMATSU BRIQUETTES CARBONIZED AND PYRIDINE CONTENT IN RAW BRIQUETTES

TABLE 1—CHARACTERISTICS OF COALS USED

COAL	PROXIMATE ANALYSIS				ULTIMATE ANALYSIS (D.A.F.)		
	Moisture	Ash	Volatile matter	Fixed carbon	C	H	O+N+S
	%	%	%	%	%	%	%
Bibai	4·2	5·6	41·1	49·1	79·3	5·9	14·8
Takamatsu	4·7	11·2	39·3	44·8	78·2	5·8	16·0

TABLE 2—SIEVE ANALYSIS OF COALS USED

COAL	Mesh (Tyler) % +100	100–200	200–375	−375
Bibai	2·0	47·5	49·5	1·0
Takamatsu	2·1	57·3	39·6	1·0

TABLE 3—BRIQUETTING OF BIBAI COAL IMMERSED IN VARIOUS LIQUIDS

LIQUID	ABSORPTION TIME *hr.*	LIQUID CONTENT %	BRIQUETTE PRESSURE *kg./sq.cm.*	RAW BRIQUETTES		CARBONIZED BRIQUETTE	
				Apparent density	Brinnel hardness No.	Apparent density	Shore hardness No.
Pyridine	..	..	1000	0·98	2·10	1·18	40
			2000	1·04	5·26	1·25	45
do	48	7·6	1000	1·02	5·51	1·24	49
			2000	1·10	14·90	1·33	66
do	72	10·2	2000	1·15	9·80	1·36	68
			1000	1·02	6·45	1·23	51
do	96	13·5	2000	1·10	9·25	1·31	58
Benzene	24	4·3	1000	0·99	4·27	1·19	45
			2000	1·06	7·15	1·29	56
do	48	5·8	1000	0·99	4·76	1·20	46
			2000	1·07	6·81	1·29	57
do	96	6·7	1000	1·00	3·09	1·19	43
			2000	1·07	6·04	1·27	55
Tar base	4	0·5	1000	1·00	..	1·17	56
			2000	1·09	..	1·26	62
do	24	1·9	1000	1·01	..	1·20	..
			2000	1·09	..	1·25	71
			1000	1·03	..	1·20	50
do	48	2·3	..	..	..	..	..
do	72	..	1000	1·06	..	..	..
Ammoniacal liquor	24	..	1000	1·01	..	1·14	..
			2000	1·09	..	1·20	..
do	48	..	1000	1·00	..	..	..
			2000	1·09	..	..	..
do	120	..	1000	1·00	..	1·03	..
			2000	1·09	..	1·24	..
Aqueous NaOH	24	(immersion)	1000	0·99	1·0	..	..

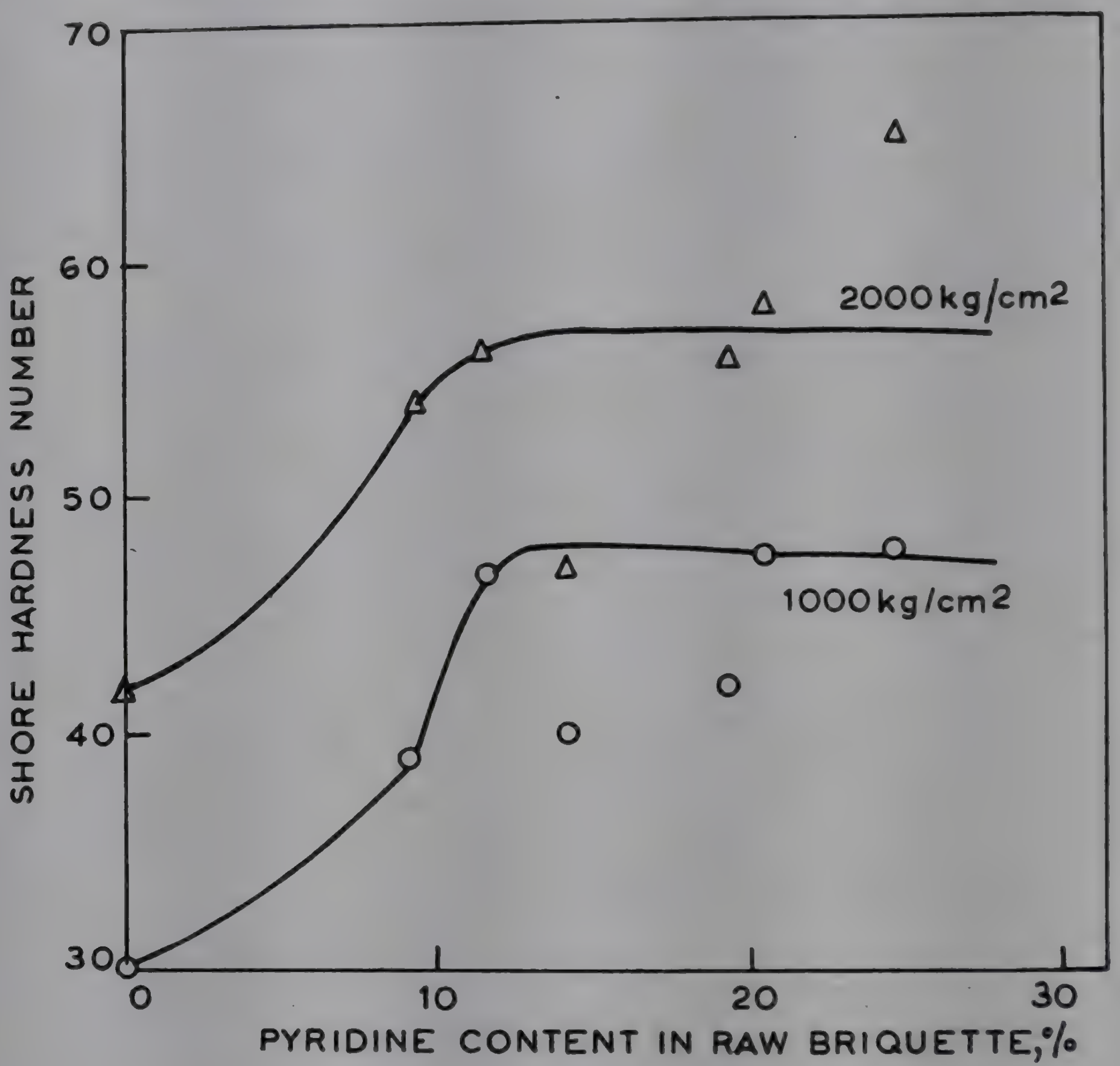

FIG. 4A—RELATION BETWEEN SHORE HARDNESS VALUE OF TAKAMATSU BRIQUETTES CARBONIZED AND PYRIDINE CONTENT IN RAW BRIQUETTES

by absorption of solvent and by decrease of the hardness value—possibly the latter is due to the release of hydrogen bonds within or between coal molecules[7].

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DISCUSSION

Dr V. A. Altekar : Coal is supposed to be heterogeneous and microhardness may differ from spot to spot. I would like to know whether the authors have taken into consideration the heterogeneity of coals.

Dr M. S. Iyengar : Though coal is heterogeneous, there is a regularity in its properties like refractive index, elasticity and elastic constants. Therefore, microhardness also may not be varying very much.

Author's written reply: In these investigations, we have assumed that the briquetted aggregates obtained from finally dispersed particles are not heterogeneous but homogeneous.

Emulsification of Tar-based Products and their Utilization as Binders for Briquetting of Coal Fines

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Studies on laboratory and pilot plant scale using briquette binders prepared by emulsification of tar products like coal tar pitch and Bōjuntan have shown that excellent emulsion-type binders could be obtained by this method. Sulphite waste liquor was found to be a strong dispersing agent for tar products forming thin, stable, O-W type emulsion (water soluble) having a ratio of 50:50 of tar product and water. Coal fines of high moisture content were mixed with 10-15 per cent of emulsion binder, and briquetted at room temperature in a cylindrical or egg-shaped mould. After drying, the briquettes showed excellent compression strength, high resistance to drum test and satisfactory waterproofing qualities. The smoke-producing characteristics are largely eliminated and more uniform combustion can be obtained. These emulsion briquettes can be used not only as locomotive fuel but also for industrial and domestic purposes.

The proportion of fines in run-of-mine coal has gradually increased with increasing adoption of mechanical mining methods. Especially, with the adoption of hydraulic mining and transportation of coal the production of coal fines of high moisture content will further increase in the near future. Effective utilization of these has become an important problem for the mining industry and the briquetting industry is consequently confronted with the problem of briquetting these fines. To meet this situation, the possibility of briquetting of these low-grade coal fines with tar-based emulsion binder was investigated.

The main advantages of this process over the normal pitch-bound briquetting process in which coal and pitch are heated together with direct steam, are as follows:

(1) Coal fines of high moisture content can be briquetted without drying at room temperature.
(2) Heat consumption in briquetting is relatively low and a remarkable reduction of binder is expected.
(3) Briquette shows an excellent compression strength, satisfactory water resistance and good weathering characteristics.
(4) As the briquettes are of uniform quality, favourable burning conditions are maintained as well as a reduction in smoke forming characteristics.

EMULSIFICATION OF TAR-BASED PRODUCTS AND RESULTS

The tar-based products, for instance, coal-tar pitch and Bōjuntan could be emulsified as briquette binder of O-W type emulsion, and the following conditions were fully satisfied.

(1) The bituminous substances used should be of proper type and should possess the right properties.
(2) The dispersing and the stabilizing agent (in colloidal state) should be properly selected and used in right proportion.
(3) Proper emulsifying temperature should be used.
(4) Water used as dispersion medium should be of proper *p*H and of proper proportion in emulsion.

Some experiments have been carried out to study the influence of above factors on the emulsification of tar-base products. In general, it was difficult to emulsify a material of high melting point and low penetration index, and the emulsion so produced could not be used as a briquette binder at room temperature. The suitable raw bituminous matter for emulsification should have a melting point of 30°–60°C. Bituminous emulsion of high asphaltene content is more desirable as a briquette binder, but is difficult to produce.

Cation-active surfactants, especially amine bases, were useful dispersing agents, but did not give the best results, except the combination of two or more.

For industrial purpose, the sulphite waste liquor was found to be the strongest and cheapest and most suitable emulsifying agent. Its analysis and properties are given in Table 1.

Stability of the emulsion could be improved by the strong mechanical dispersion technique and the use of optimum bituminous particle size which in the present case ranged 1–10 microns in diameter. It was more effective to add some quantities of colloidal substances to obtain a complete state of emulsion.

Sodium carboxy methyl cellulose (CMC) was used for this purpose, but the actual amount (in the range 0·3–1·0 per cent of water) had to be adjusted according to the required stability and viscosity.

In the emulsifying operations, if the melting point of raw bituminous matter was controlled below 80°C., the temperature at which the emulsion converts its phase from O-W type to W-O type was perhaps remaining stationary, in spite of the difference of melting point. On the other hand,

TABLE 1—ANALYSIS AND PROPERTIES OF SULPHITE WASTE LIQUOR

Specific gravity (20°C.)	1·260
*p*H	5·4
Solid matter, g./100 cc.	58 90
Ash content, %	6·69
Calcium, %	4·45
Methoxyl group, %	3·80
Ligninsulphonic acid, %	32·90

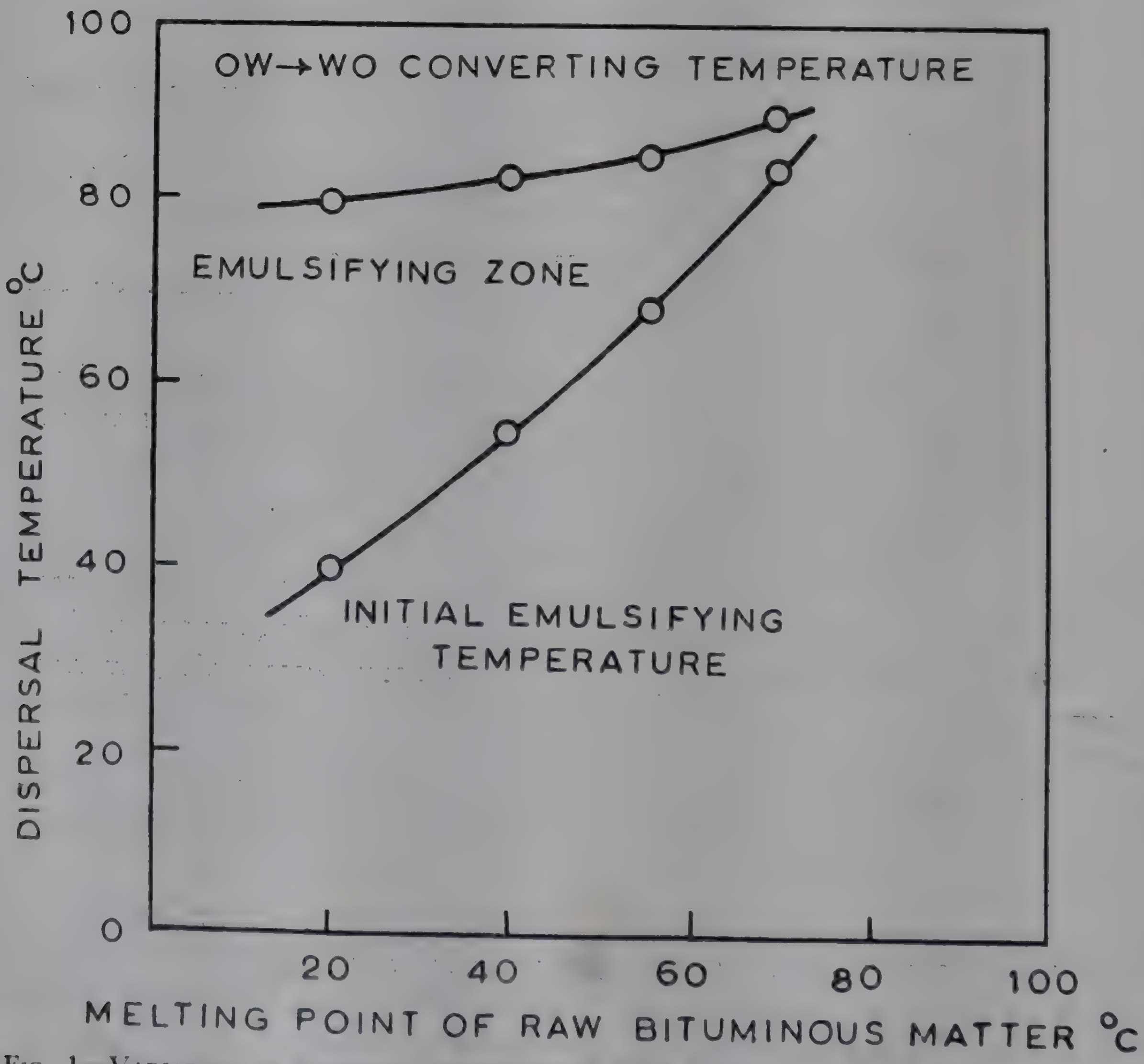


FIG. 1—VARIATION OF DISPERSAL TEMPERATURE WITH MELTING POINT OF RAW BITUMINOUS MATTER

the initial emulsifying temperature gradually increased with rise in melting point. As such, the emulsifying zone for high melting bituminous matter was reduced as can be seen from Fig. 1 and some difficulty might be encountered. But experience has shown that the converting temperature could be raised, as shown in Fig. 2, by increasing the amount of dispersing agent when it was possible within limits to emulsify bituminous matter of high melting point. Water as dispersion medium must be modulated from 30 to 50 per cent content in emulsion. Fig. 3 shows the relation between the viscosity and the consistency of produced emulsion. The *p*H of dispersion medium, after the addition of sulphite waste liquor was 5-6. Based on these results, the following industrial technique was evolved to produce the emulsion. The bituminous matter was heated to 90°-110°C. to obtain a fluid state in a melting tank, and the dispersion medium containing adequate quantity of sulphite liquor and CMC was heated to 60°-90°C. in another tank. Measured amounts of each were fed in the desired proportion to a steam-jacketted colloid mill (6,000-12,000 r.p.m.), and the two were mixed together and dispersed in a O-W type emulsion at a temperature of about

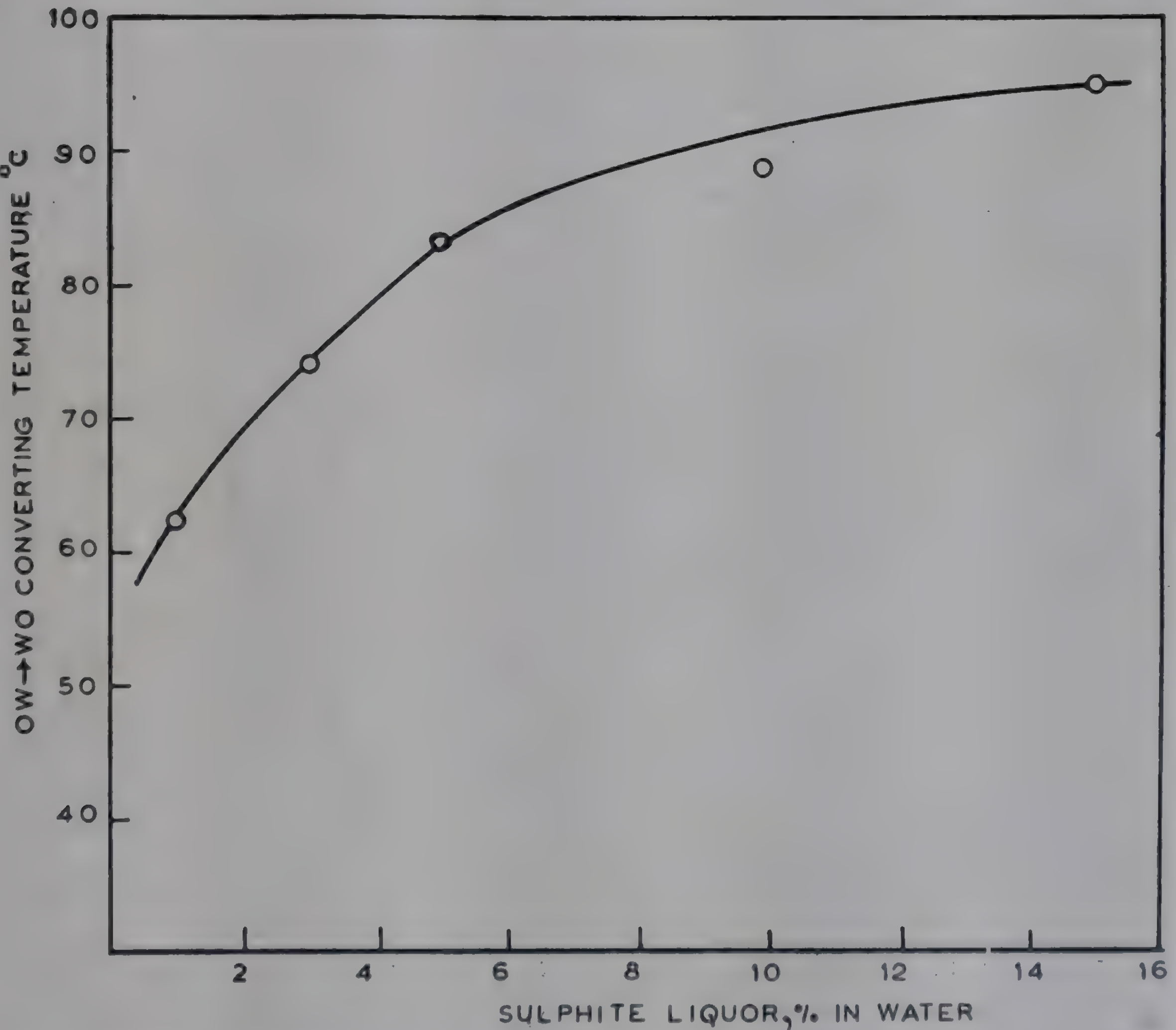


FIG. 2—EFFECT OF INCREASING THE DISPERSING AGENT ON OW→WO CONVERTING TEMPERATURE

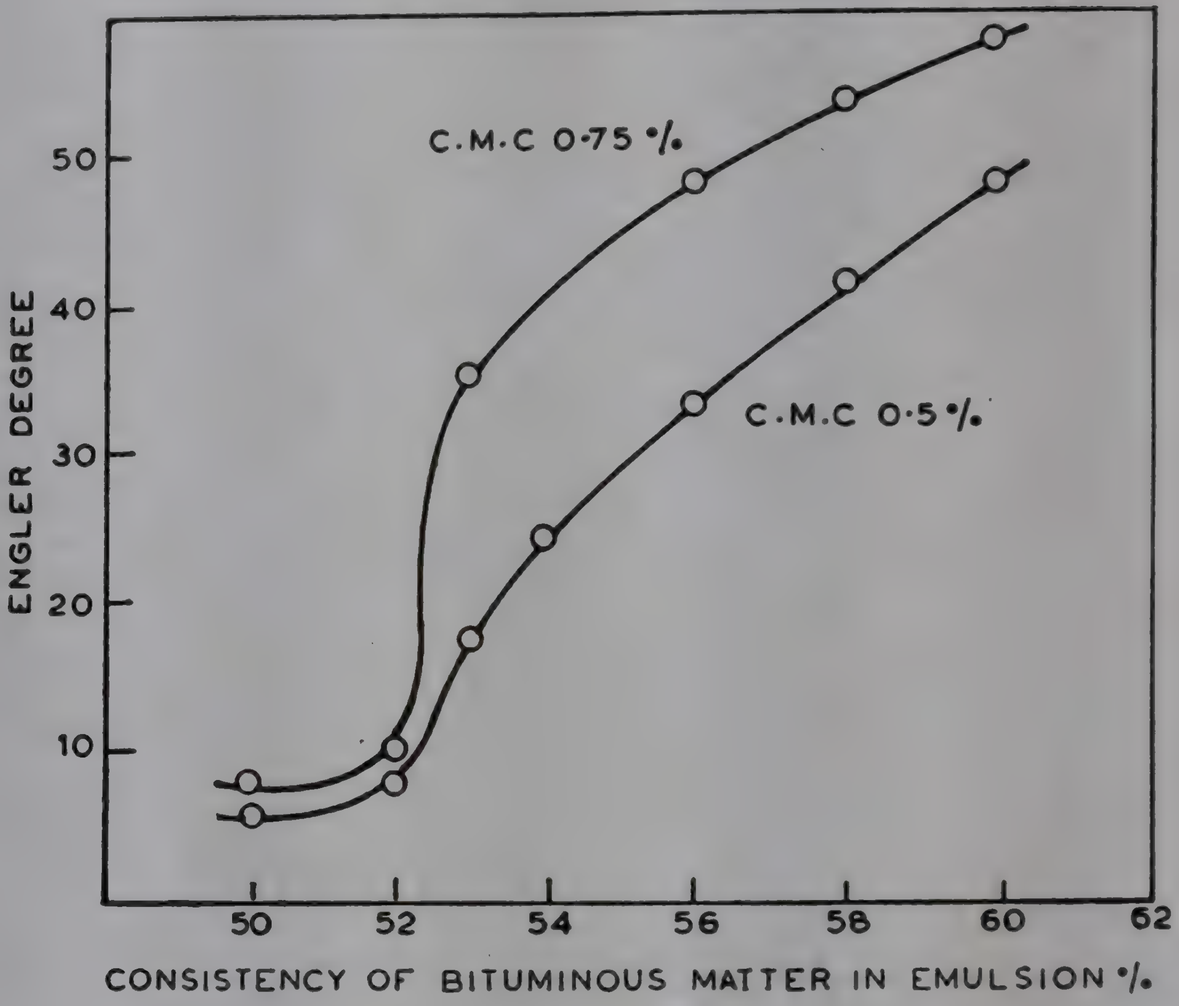


Fig. 3—Relationship between viscosity and consistency of emulsion

70°-90°C. Emulsifying conditions and the properties of the emulsions thus produced are shown in Table 2. Fig. 4 is a photomicrograph of emulsion.

These emulsions have satisfactory flow characteristics, stabilities during a long period of storage and no danger from fire hazards and do not have any objectionable odour or fume.

LABORATORY TESTS ON THE EMULSION BRIQUETTE

As soon as the emulsion is added to coal fines it distributes itself throughout the coal by mixing operation and reaches the surface of each coal particle. At this stage the emulsion breaks down and water ceases to be the continuous phase of the emulsion and continuous bituminous films are formed covering the surface of coal. If the material is now briquetted, the free water is squeezed out and the bonding power of the bituminous substance becomes excellent. It is advisable that the material should consist of adequate amount of surface moisture, as it could help the dispersing action of emulsion.

TABLE 2—COMPOSITIONS OF EMULSIONS AND CONDITIONS OF EMULSIFICATION

BITUMINOUS MATTER	MELTING POINT (°C.) JIS. K-2531	COMPOSITION OF EMULSION (%)				EMULSIFYING CONDITIONS TEMPERATURE (°C.)			ENGLER DEGREE (at 25°C.) JIS. K-2208	STABILITY (%) (for 5 days) JIS. K-2208
		Bituminous matter	Water	Sulphite liquor	C.M.C.	Bituminous matter(°C.)	Dispersion medium	Emulsification		
Bōjuntan	50	50	44·55	5	0·45	100	80	85	25·2	5·0
do	40	50	44·55	5	0·45	100	70	80	12·5	4·0
do	30	50	44·55	5	0·45	80	60	75	9·8	4·0
Pitch	50	50	44·55	5	0·45	100	80	85	6·3	2·5
do	40	50	44·55	5	0·45	90	80	80	5·2	2·0

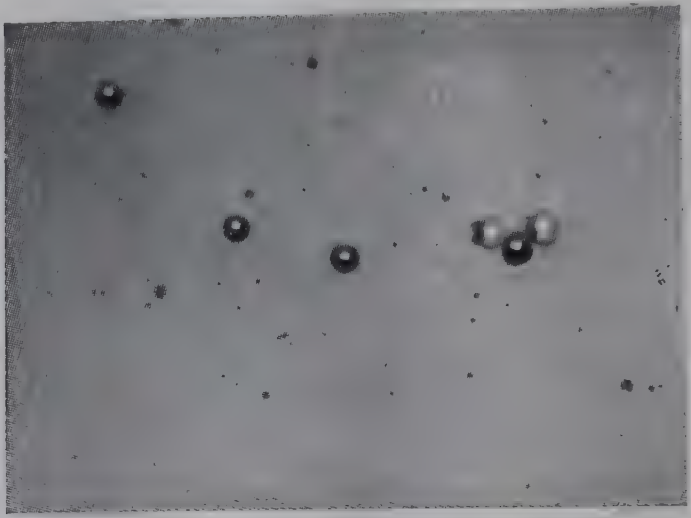
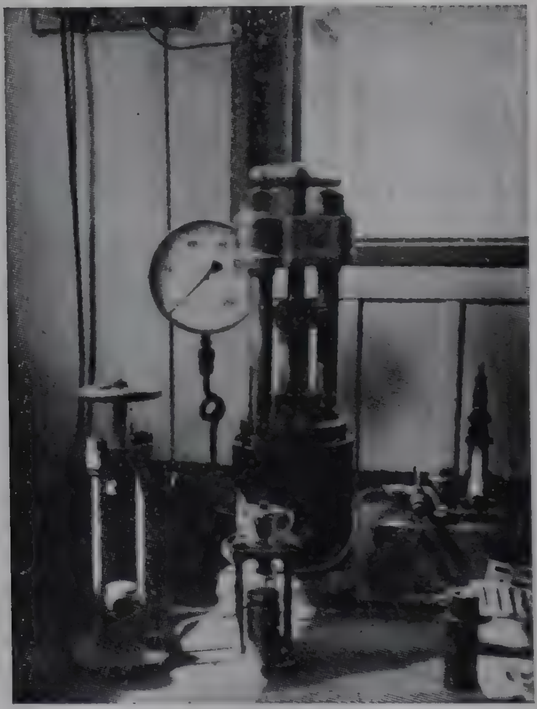


FIG. 4—PHOTOMICROGRAPH OF EMULSION

FIG. 5—OIL PRESS



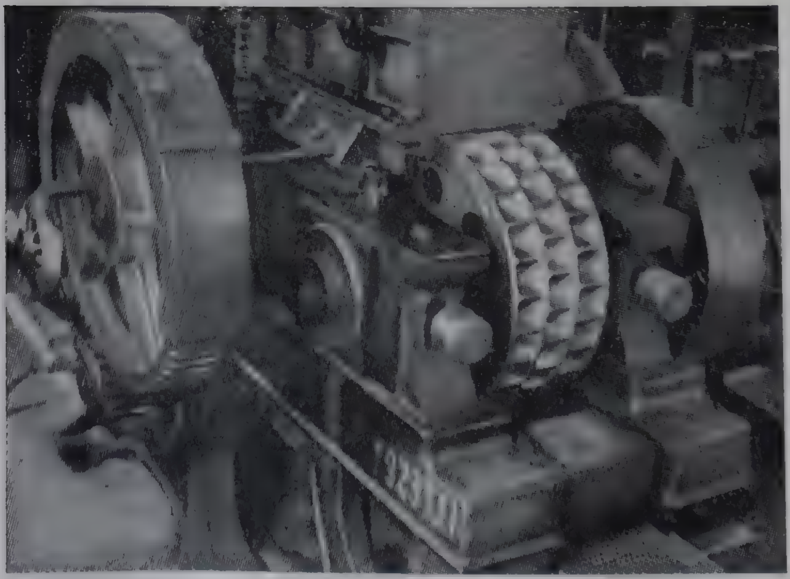


FIG. 6—ROLL PRESS 7·5 h.p., 11 r.p.m.

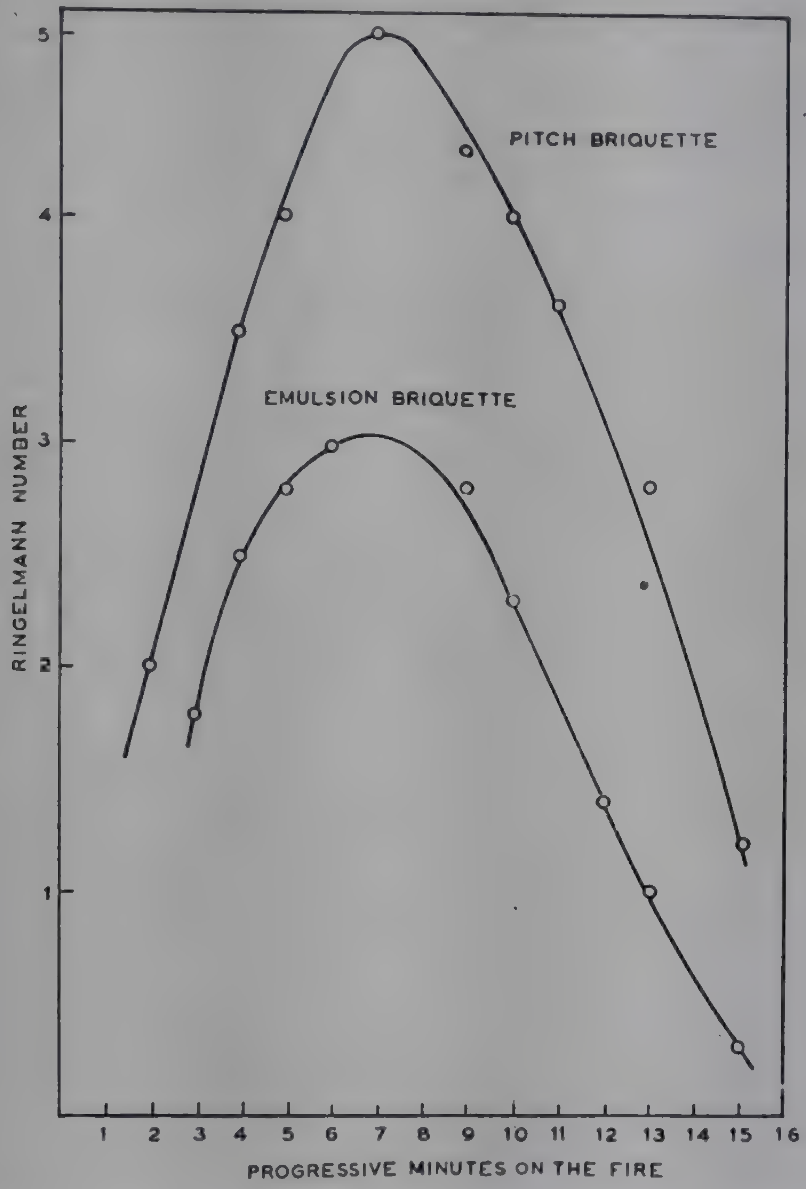


FIG. 7—SMOKE PRODUCING CHARACTERISTICS OF PITCH BRIQUETTE AND EMULSION BRIQUETTE

Generally speaking, the emulsion has been found to be a suitable binder for wet coal fines, reducing the binder consumption to almost its theoretical value. Physical properties like compression strength, baking characteristics, water-resistance and weathering qualities of the resultant briquette are affected by the following variables:

(1) Nature of coal, surface moisture and particle size.
(2) Type and per cent of binder in the blend.
(3) Briquetting pressure.
(4) Method of drying (by air or in ovens).

A series of laboratory tests were made in an attempt to explain the inter-dependence of these factors.

After a definite amount of emulsion binder (shown in Table 2) is blended and mixed thoroughly with cold coal fines (screen analysis given in Table 3), the mixture was directly pressed by oil press (Fig. 5) (at room

TABLE 3—SCREEN ANALYSIS OF COAL FINES (NON-CAKING)

	%
+ 20 mesh	11·85
20—60 mesh	46·09
60—100 mesh	20·90
100—200 mesh	15·89
− 200 mesh	5·27

temperature) in a cylindrical mould of 20 mm. length and 20 mm. diam. The test pieces prepared under the following conditions were examined for their compression strength: (*a*) cold air drying for few days, (*b*) drying at 105°C. for 1 hr, and (*c*) carbonizing at 600°C. for 5 min.

The preliminary experiment gave the following results: (1) Compression strength of briquette increased with increasing moulding pressure, from a value of 1·6 times at 200 kg./sq. cm. to 4·1 times at 400 kg./sq. cm. compared to that at 100 kg./sq.cm. (2) Lignite, when briquetted and tested similarly, owing to its inner moisture, did not show such a satisfactory result. (3) Fine coals gave better results than coarse coal.

Further, for convenience, the briquetting pressure was standardized at 225 kg./sq. cm. as obtained in the roll press. The effects of various variables like the type and percentage of binder, the surface moisture of coal, etc. on the properties of briquettes were determined. The results are as follows:

The Effect of Type and Percentage of Emulsion Binder. Pitch emulsion binder was employed for the coal fines with a surface moisture content of 10 per cent. The operation data and results given in Table 4 show that: (*i*) Emulsion binder is required to the extent of 10 to 15 per cent on the coal and becomes rather excessive at 20 per cent, (*ii*) emulsion of high melting point pitch showed the desirable qualities as binder, (*iii*) air drying for at least three days is necessary to get the maximum effect of the binder; thus it is better for industrial purposes to dry them by hot air, and (*iv*) as the compression strength of carbonized emulsion briquettes being 5-10 kg./sq. cm. there is no fear of deformation on the fire.

The Effect of the Surface Moisture of Coal. Coal fines of different surface moisture contents were briquetted employing the Bōjuntan-emulsion binder and results are presened in Table 5. It was observed that: (*i*) The optimum surface moisture of coal was in the range of 0-10 per cent and the presence of adequate moisture facilitated the briquetting process, (*ii*) a comparison of Tables 4 and 5 shows that the Bōjuntan-emulsion was superior to pitch-emulsion under similar conditions, and

TABLE 4—EFFECT OF TYPE AND PERCENTAGE OF EMULSION BINDER ON THE PROPERTIES OF BRIQUETTES

Emulsion		Compression strength (kg./sq.cm.)				Water resistance
Melting point of pitch emulsified	Percent of blend (dry-basis)	Obtained by air drying			Obtained by hot drying at 100°C. for 1 hr	
		After 1 day	After 3 days	After 6 days		
30°C.	10 (5%)	2·0	9·8	11·0	21·9	Satisfactory
do	15 (7·5%)	2·8	18·5	20·8	23·9	do
do	20 (10·0%)	3·5	25·0	32·6	26·8	do
40°C.	10 (5·0%)	5·2	22·2	20·6	34·8	do
do	15 (7·5%)	6·5	54·9	60·0	44·2	do
do	20 (10·0%)	1·3	40·6	60·0	28·6	do
50°C.	10 (5·0%)	1·5	8·2	12·7	17·5	do
do	15 (7·5%)	4·9	45·1	46·0	72·0	do
do	20 (10·0%)	6·1	47·4	66·0	89·7	do

Figures in brackets show % absolute pitch

TABLE 5—EFFECT OF SURFACE MOISTURE OF COAL ON THE PROPERTIES OF BRIQUETTES

Surface moisture of coal (%)	Emulsion		Compression strength (kg./sq. cm.)				Water resistance
	Melting point of Bōjuntan emulsified	% of blend (dry-basis)	Obtained by air drying			Obtained by hot air drying at 105°C. for 1 hr	
			after 1 day	after 3 days	after 6 days		
0	30°C.	15 (absolute Bōjuntan 7·5%)	19·60	32·83	40·18	37·73	Satisfactory
5	do	do	16·66	26·95	32·83	38·71	do
10	do	do	16·37	26·46	31·26	45·57	do
20	do	do	6·37	27·44	27·44	33·83	do
0	40°C.	do	27·93	37·24	36·85	53·90	do
5	do	do	34·79	32·34	35·77	62·72	do
10	do	do	31·95	34·79	30·87	56·35	do
20	do	do	23·52	34·50	30·38	38·22	do
0	50°C.	do	19·60	53·40	49·30	56·40	do
5	do	do	15·20	55·80	57·80	71·00	do
10	do	do	9·30	49·00	51·00	63·70	do
20	do	do	34·18	54·40	55·13	40·70	do

TABLE 6—SCREEN ANALYSIS OF SHORO COAL SLUDGE

(Non-caking)	%
+ 20 mesh	30·9
20— 60 mesh	46·1
60—100 mesh	10·4
100—200 mesh	10·4
—200 mesh	2·2

TABLE 7—RESULTS OF PILOT PLANT TRIALS ON EMULSION BRIQUETTING

Expt No.	Blending of emulsion, % (dry-basis)	Composition of briquette % (dry-basis)			Moisture of mass %	Strength of briquette obtained drying at 105°C. for 1 hr	
		Fine coal	Tar pitch	Anthracene oil		Compression strength kg./sq. cm.	Trommel index at 25 r.p.m. for 2 min.
1	10	94·73	3·95	1·32	13·87	48·5	72·5
2	15	91·77	6·19	2·04	15·70	66·0	93·0
3*	15	91·77	6·19	2·04	15·70	54·3	91·4

* Coarse Shoro coals are briquetted at the same composition as in Experiment No. 2

(*iii*) the strength of carbonized Bōjuntan-emulsion briquette was higher than that of pitch-emulsion briquette.

In spite of the existence of close correlation between the decomposition phenomena and the exhibition of its binding power, a tar-base emulsion does not show such rapid decomposition as an asphalt emulsion. To eliminate these handicaps various methods have been tried. But this requires a further intensive study.

MANUFACTURING OF EMULSION BRIQUETTE AND ITS COMBUSTION TEST

To confirm the laboratory results, trials were performed using a double-roll press. Shoro coal sludge from settling ponds (10·3 per cent moisture content) was used as raw coal. Its screen analysis is shown in Table 6.

Coal-tar pitch whose melting point was lowered from 70° to 40°C. by adding 30 per cent of anthracene oil was emulsified by sulphite liquor as dispersion agent to the consistency of 50 per cent pitch in emulsion. After blending the above emulsion (10-15 per cent on coal fines) the mass was ground into a homogeneous mixture for 5 min., using an edge runner at 25 r.p.m. The mixture was briquetted at room temperature, each briquette weighing approximately 50 g. in a roll press of 2 ton/hr capacity (Fig. 6). The results are given in Table 7.

These results have shown that: (*i*) pilot-plant trials confirm to those of laboratory tests, (*ii*) briquettes for industrial or domestic purpose can be obtained using 10-15 per cent of emulsion binder and had trommel index above 60 against 85 for locomotive use, and (*iii*) much attention must be given to the problem of moisture of the mass which comes from coal and emulsion. If it exceeds 18-20 per cent, the continuous briquetting may not be possible by roll press. Combustion tests of No. 2 briquette (in Table 7) showed that they hold together until completely burnt without disintegration on the fire. A remarkable reduction in the smoke-producing characteristics can be seen in Fig. 7.

As to the economics, it can be said that the briquettes prepared by this method will be cheaper by about 40 to 60 per cent than the usual pitch briquettes, mainly due to reduction in the installation and operation costs and also of raw coal.

Hardness of Briquetted Coal

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Binderless briquetting is controlled by the mechanical properties of coal. Hardness of coal is related to mechanical properties, especially elastic and plastic properties of coal. The relation between briquettability and rank of coal is thus closely connected with the relation between hardness and rank of coal.

Apparent density, compressive strength and indentation hardness of briquette increase with the pressure of briquetting, reaching optimum values at about 2000 kg./sq.cm.

Non-uniformity of briquettes as shown by indentation hardness is affected by pressure, height of briquette, lubricant and is due to friction between coal particles and wall of mould. Slight crack of briquette caused by the expansion of briquette while coming out of the mould is affected by the taper of mould.

In general, fine coal powder can be briquetted by pressure alone. Many investigations on binderless briquetting of powdered coal have been carried out and the relation between the briquetting and the various factors such as rank, particle size, moisture content, ash content, briquetting pressure and briquetting method have been discussed[1].

The area of contact among the particles is a fundamental factor in the briquetting of powders and is controlled by the mechanical properties such as elasticity or plasticity of the particles. On the other hand, the hardness measurements are used as a means of assessing the general mechanical properties of materials. Young's modulus, the elastic limit, the full plasticity limit, the fraction of elasticity and plasticity, etc. of coal are deduced from the hardness of coal[2-4].

Therefore, the briquettability of coal, the heterogeneity of coal briquettes, the most suitable type of moulding die and other factors have been investigated on the basis of the hardness measurements of coal or coal briquettes.

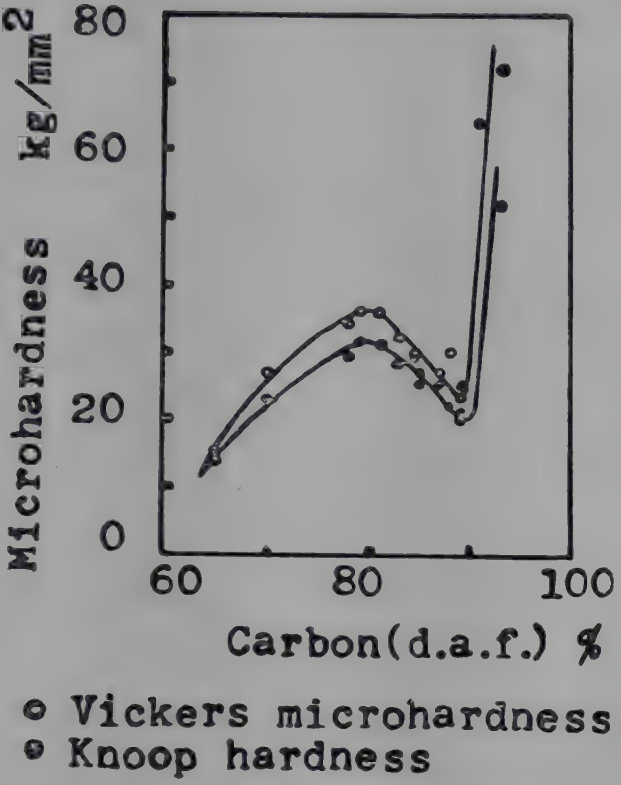

Fig. 1—Relation between microhardness number and rank of coal

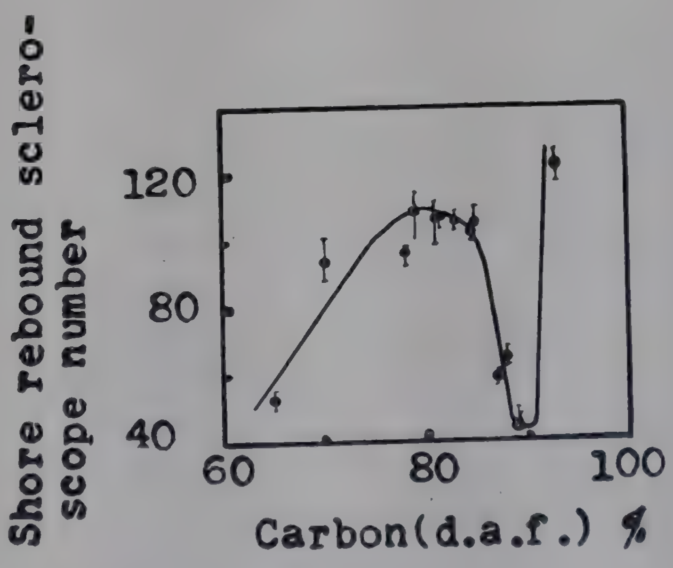

Fig. 2—Relation between Shore rebound scleroscope number and rank of coal

HARDNESS OF COAL

The static indentation hardness number (ordinary Vickers hardness number, Vickers microhardness number, Knoop hardness number, Brinell hardness number, etc.) and the dynamic hardness number (Shore rebound scleroscope number, etc.) of vitrain change with rank of coal. Fig. 1 shows the relation between microhardness number and rank of coal[3], and Fig. 2 the relation between Shore rebound scleroscope number and rank of coal[4].

For lignite, brown coal and non-caking coal, the hardness number increases with rank and reaches a maximum at about 80 per cent carbon content. For caking and coking coals the hardness number decreases with

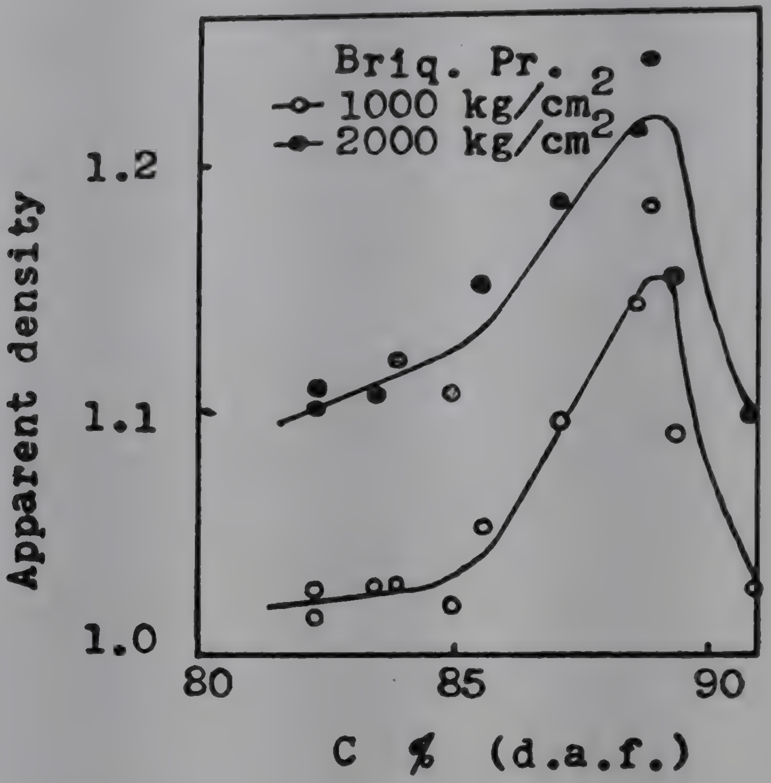

Fig. 3—Relation between apparent density and rank of coal

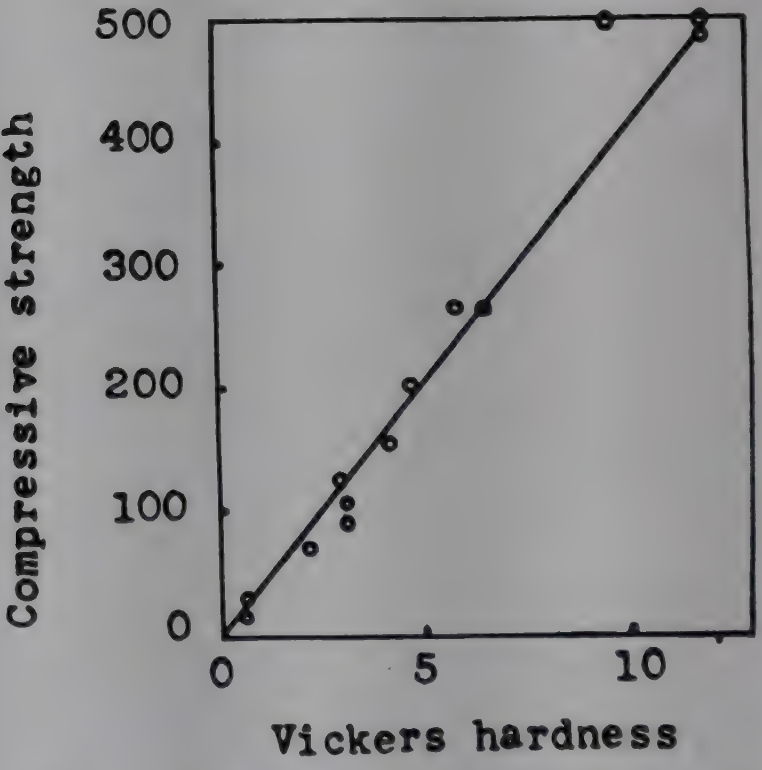

Fig. 4—Relation between compressive strength and Vickers hardness of coal briquettes

rank to a minimum at about 90 per cent carbon content; for anthracite the hardness number suddenly increases again.

BRIQUETTABILITY OF COAL

The relation between the compressive strength of briquettes and the rank of coal was studied by Iyengar and Subramanian[5]. In the present investigation the apparent density of briquettes obtained from various vitrain powders (90 per cent through 200 Tyler mesh sieve) is measured using the moulding die of type III mentioned below. Fig. 3 shows the relation between the apparent density of briquettes and rank of coal[6]. As the variation of true density with rank is smaller than that of apparent density, the compactness of briquettes is approximately represented by the apparent density of briquettes.

The relation between the compressive strength or the apparent density of briquettes and rank of coal agrees well with that between hardness and rank of coal. The compressive strength of briquettes decreases with the increase of hardness of coals over the range 70 to 80 per cent carbon content. The compressive strength and the apparent density of briquettes increase with the decrease of hardness of coals over the range of 80-90 per cent carbon content and decrease again with the increase of hardness of coals beyond about 90 per cent carbon content. Thus the lower the hardness of coal, the greater is its briquettability.

For caking coal the briquettability increases with rank, though the contribution of the chemical cohesive force such as hydrogen bonding decreases[7,8]. This shows that the contribution of the mechanical properties of coal relatively becomes larger, though the contribution of van der Waal's force must also be considered.

In briquetting of powdered coal, other conditions remaining constant, the higher the briquetting pressure, the longer the compression duration, the slower the compression speed, the higher the strength of briquettes which finally becomes steady. The effect of briquetting pressure is the most important of all[1].

The apparent density, the compressive strength, and the Vickers hardness of briquettes increase with the briquetting pressure and become constant at about 2000 kg./sq.cm.[6] This pressure almost corresponds to the limit of the full plasticity of coal which is deduced from the indentation hardness number of coal. The relation between the compressive strength and the Vickers hardness of briquettes is linear as shown in Fig. 4. Therefore, the indentation hardness of briquettes shows the strength of briquettes. The relation between the porosity and the Vickers hardness of briquettes is linear as shown in Fig. 5 for the same kind of coal. Consequently, the indentation hardness of briquettes is proportional to the compactness or the density of briquettes.

HARDNESS DISTRIBUTION IN COAL BRIQUETTES

The heterogeneity of stress or density in the materials moulded from powders is caused by the non-uniform transmission of compression force, because powders in the moulding die do not move like the perfect liquid. So far very few detailed investigations on heterogeneity in the coal briquettes

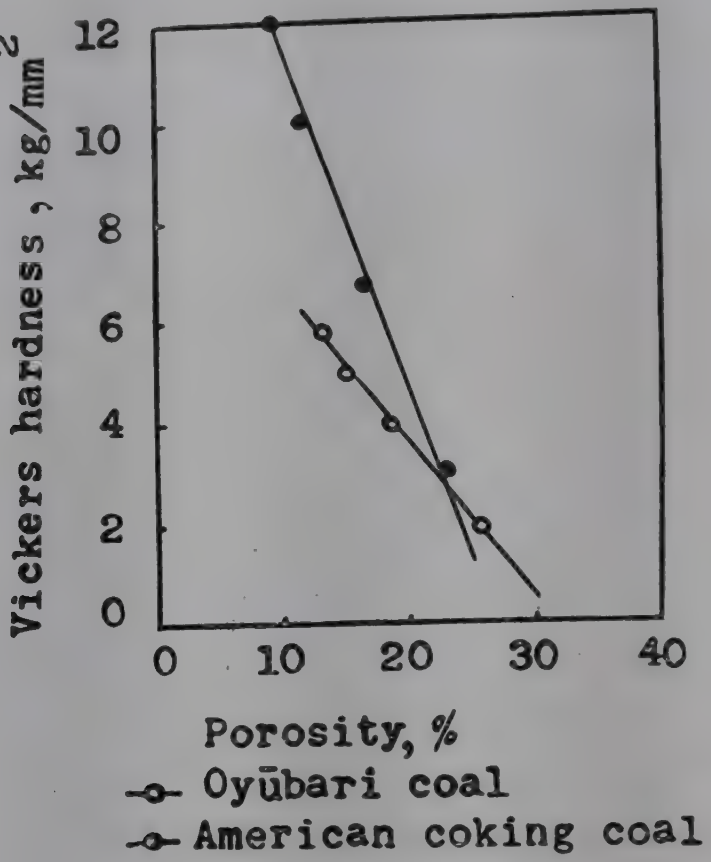

Fig. 5—Relation between Vickers hardness and porosity of coal briquettes

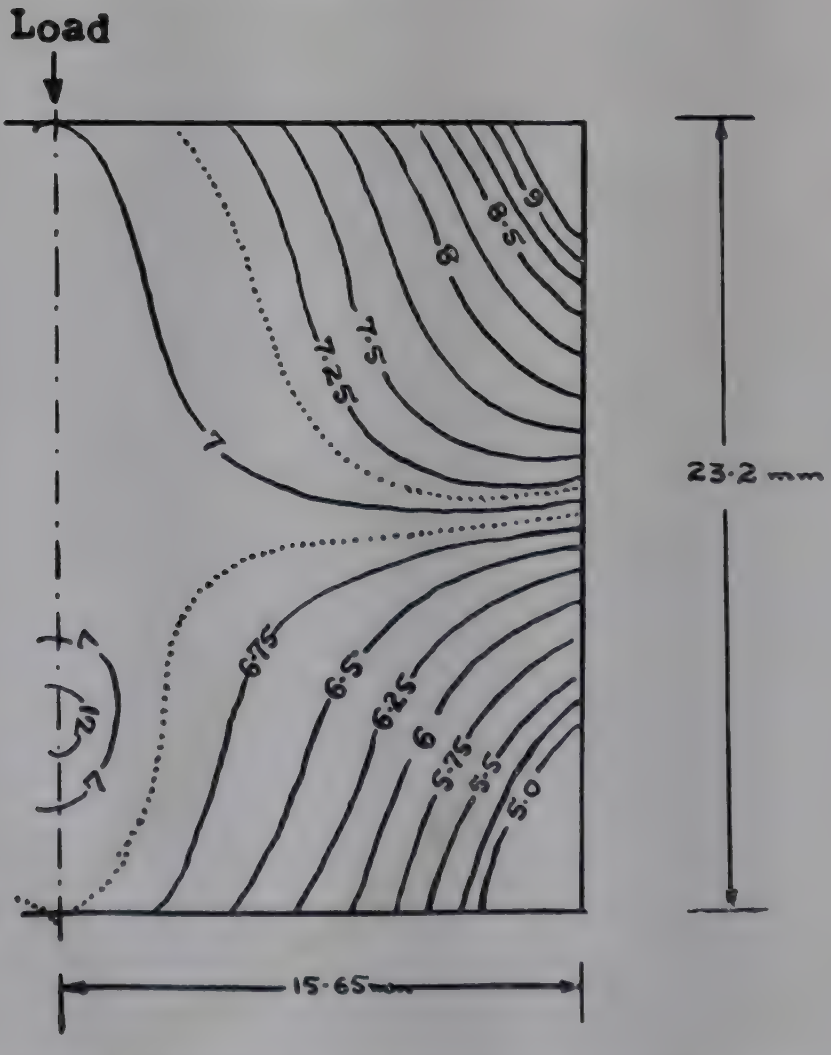
Load
9
8.5
8
7.5
7.25
7
12
7
7
6.75
6.5
6.25
6
5.75
5.5
5.0
23·2 mm
15·65 mm

Fig. 6—Hardness distribution in the cylindrical briquette of Itmann coal

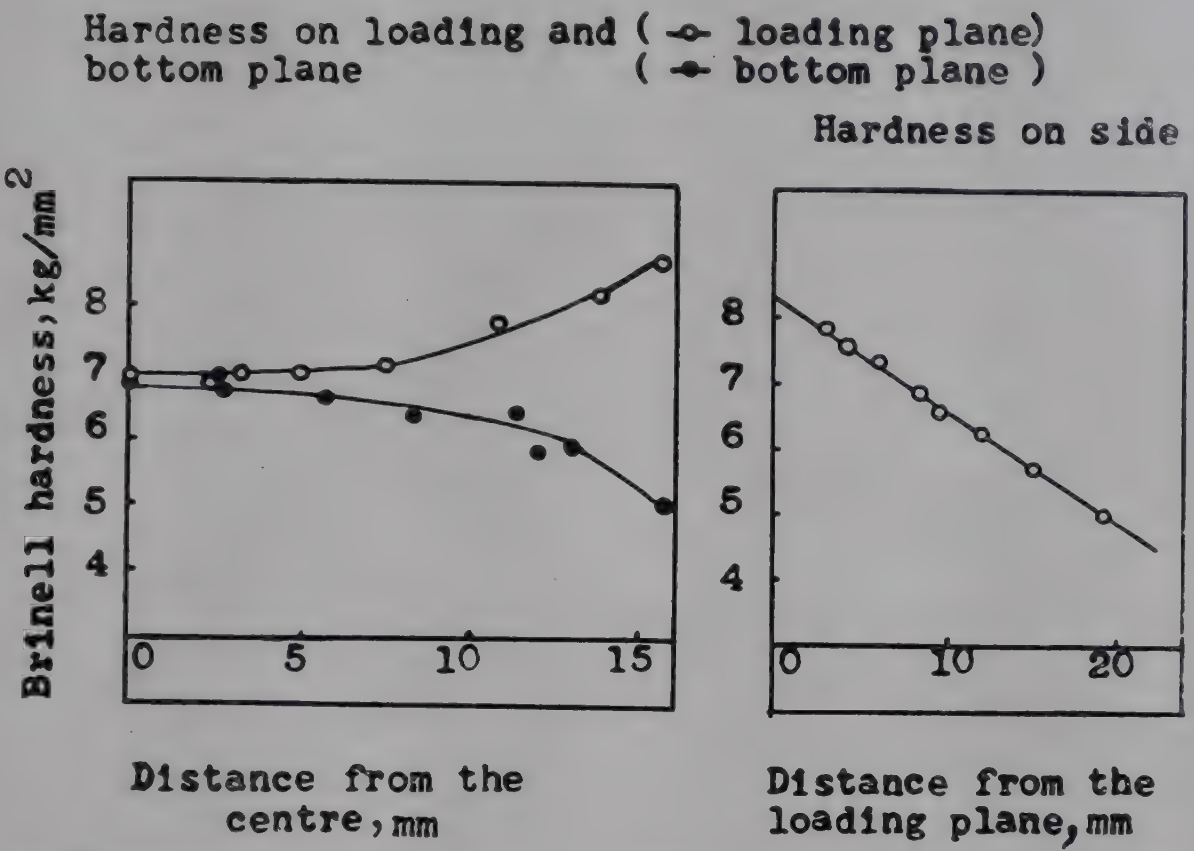

Fig. 7—Hardness distribution on the cylindrical briquette obtained from Itmann coal added 4 per cent graphite under briquetting pressure of 1000 kg./cm^2.

have been made even though some study of the non-uniformity in the moulded materials has been done in the powder metallurgy[9] and brick moulding[10].

Non-uniformity in coal briquettes has been studied by measuring the distribution of Brinell hardness number (1/16 in. ball) in the vertical section of briquettes. Fig. 6 shows the hardness distribution in the vertical section of cylindrical briquette compacted in a single direction under a pressure of 1000 kg./sq. cm. It may be concluded that a maximum hardness or a maximum density exists in the upper portion of the cylinder near the die wall, while in the lower portion a zone of maximum hardness exists in the centre. Accordingly it is clear that the friction effect between the powders and the die walls is an important cause of the non-uniformity in briquettes. Therefore the non-uniformity of briquettes shown by the hardness distribution on the loading plane, the bottom plane, and the side plane of briquettes decreases with the decrease of the height of briquettes and the briquetting pressure, and it also decreases with the addition of graphite as a lubricant. Fig. 7 shows an example of this hardness distribution on briquettes.

Fig. 8 shows the relation between the hardness difference on the side of briquettes and the extrusion pressure (the maximum pressure required in extrusion of the briquetted coal from the die). This extrusion pressure shows the frictional resistance between the briquetted coal and the die walls.

Therefore the density distribution on the side of briquettes is proportional to the frictional resistance on the die walls. Consequently, it may be said that the non-uniformity of briquettes is more affected by the frictional resistance between the coal powder and the die walls than that among the coal particles themselves.

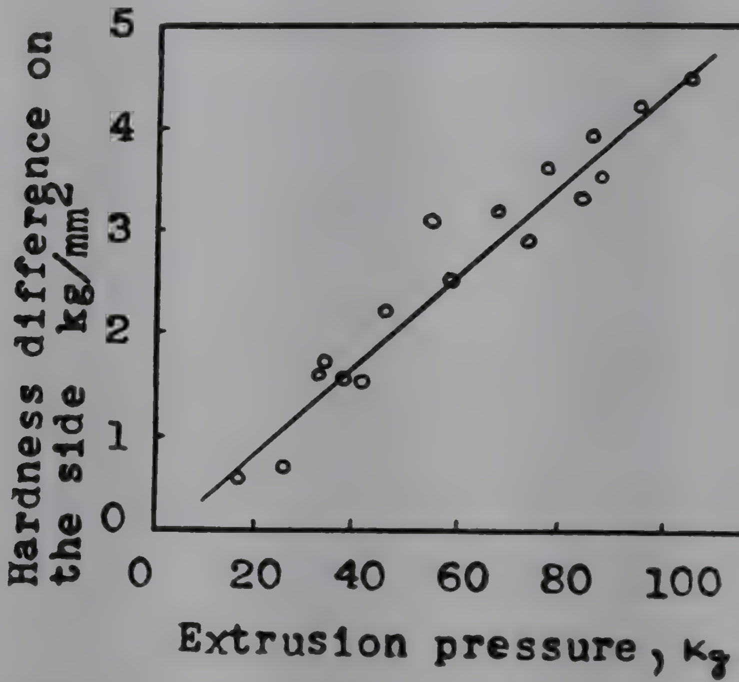

FIG. 8—RELATION BETWEEN HARDNESS DIFFERENCE ON THE SIDE OF BRIQUETTES AND EXTRUSION PRESSURE

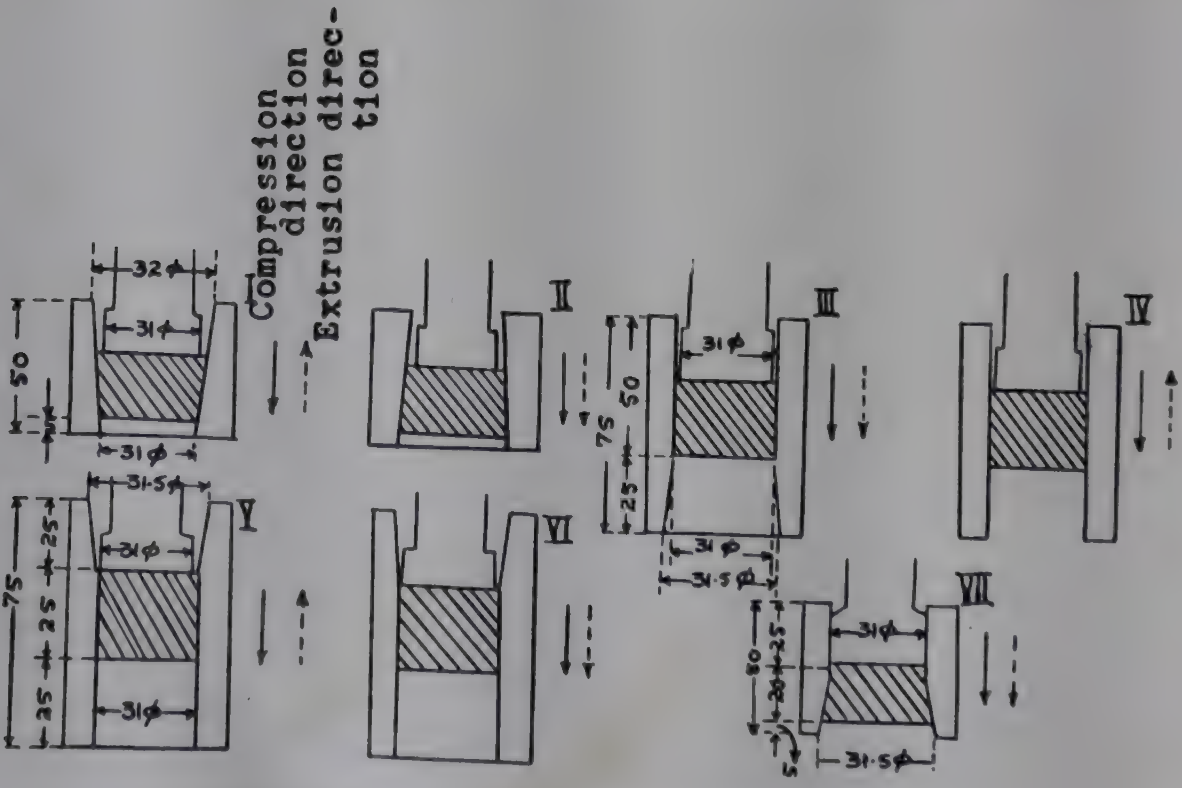
Compression direction
Extrusion direction
32ϕ
31ϕ
50
31ϕ
II
III
IV
V
VI
VII
31ϕ
50
75
25
31ϕ
31·5ϕ
31·5ϕ
31ϕ
75
25
25
25
31ϕ
31ϕ
80
25
20
5
31·5ϕ

FIG. 9—TYPES OF MOULDING DIE AND EXTRUSION METHODS

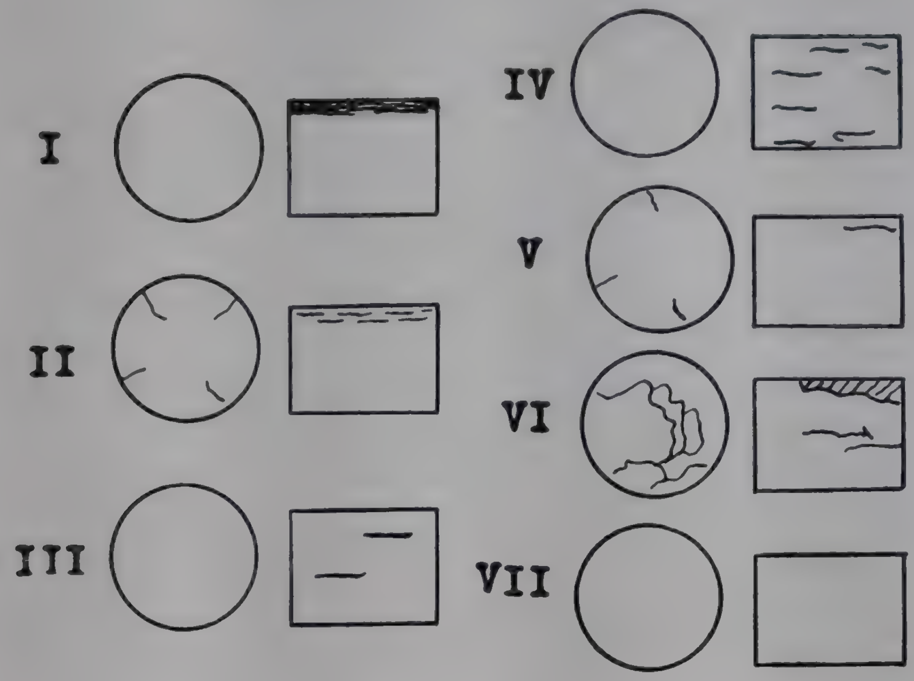

FIG. 10—TYPES OF MOULDING DIE AND CRACKING STATES ON COAL BRIQUETTES

TABLE 1—TYPES OF MOULDING DIE AND CHARACTER OF BRIQUETTES

(Sample: Itmann coal 20 g., 90 per cent passing through 200 Tyler mesh sieve; briquetting pressure: 1000 kg./sq. cm.)

TYPE	EXTRUSION PRESSURE *kg./sq. cm.*	EXTRUSION DISTANCE* *mm.*	DIMENSIONS OF BRIQUETTES, *mm.*				HARDNESS DIFFERENCE ON THE SIDE
			Height	Diameter			
				Loading plane	Centre	Bottom plane	
I	119	10·5	22·5	31·65	31·55	31·35	4·3
II	101	10·5	22·55	31·67	31·90	32·05	4·5
III	134	27·7	23·45	31·25	31·30	31·3	3·9
IV	135	22·0	23·45	31·28	31·30	31·25	3·9
V	135	28·5	23·4	31·3	31·35	31·3	5·2
VI	126	22·0	23·4	..	31·40	31·25	5·2
VII	122	11	23·1	31·3	31·5	31·65	6·2

* The extrusion distance is the moving distance of briquetted coal from the beginning of extrusion to the zero of extruding pressure, and shows the degree of expansion of briquetted coal and the allowance of expansion by the die type.

VARIOUS TYPES OF MOULDING DIES

Slight crack on briquettes is caused by the expansion of briquetted coal when it is extruded from the moulding die. This expansion increases in the order of strongly coking coal, weakly caking coal and caking coal[6].

To make homogeneous briquettes without any cracks, various types of moulding dies have been tried in the compression of a cylindrical compact in a single direction. The commonly used types of moulding dies and the extrusion direction are shown in Fig. 9. Table 1 shows the character of briquettes and Fig. 10 shows the slight crack on briquettes.

It is difficult to achieve simultaneously both the elimination of crack and the making of homogeneous briquettes in these methods. But the type III of moulding die, in which the compression part is a straight cylinder and the extrusion part has a taper permitting the slow expansion of briquetted coal, gives comparatively good results.

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DISCUSSION

Shri D. P. Agrawal: The experiments have been carried out with low-ash coals. It is known that hardness depends upon mineral matter and in these investigations ash in coal might not have been taken into consideration. I would like to know whether they considered this aspect also, as the high ash content is a problem for many Indian coals.

Author's written reply: These experiments have been done with vitrains. If the experiments are carried out on coals having ash content of the same order, similar results can be expected.

Briquetting Plant for Production of Briquettes for Low Temperature Carbonization of South Arcot Lignite at Neyveli

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The developments in the brown coal industry in Germany are reviewed with special reference to briquetting. The use of ring roll and extrusion briquetting presses for different types of coals is indicated. The briquetting plant (Extrusion type) to be erected at Neyveli (India) for briquetting lignite is described in detail, bringing out the special features of this plant, as different from other normal briquetting plants. The necessity to maintain a homogeneous and continuous supply of coal for a uniform and constant operation of briquetting plant is brought out.

PRODUCTION OF BRIQUETTES FOR LOW TEMPERATURE CARBONIZATION

Lignite, as mined, has a moisture content of approximately 45 60 per cent, due to its gel structure, and for this reason most lignites contain less than half of their weight of combustible matter. The ash content on dry basis varies from a few per cent to a level which makes its mining uneconomical. The calorific value of the lignite is only 1800-2500 kcal./kg. In addition to these inferior properties, the lignite very often reveals a low structural quality, due to its soft, earthy condition, and this is shown by the fact that considerable amounts are recovered as fines, while coarser pieces disintegrate into fines after air drying. For all these reasons lignite had only a local value when brown coal mining began in Germany at the

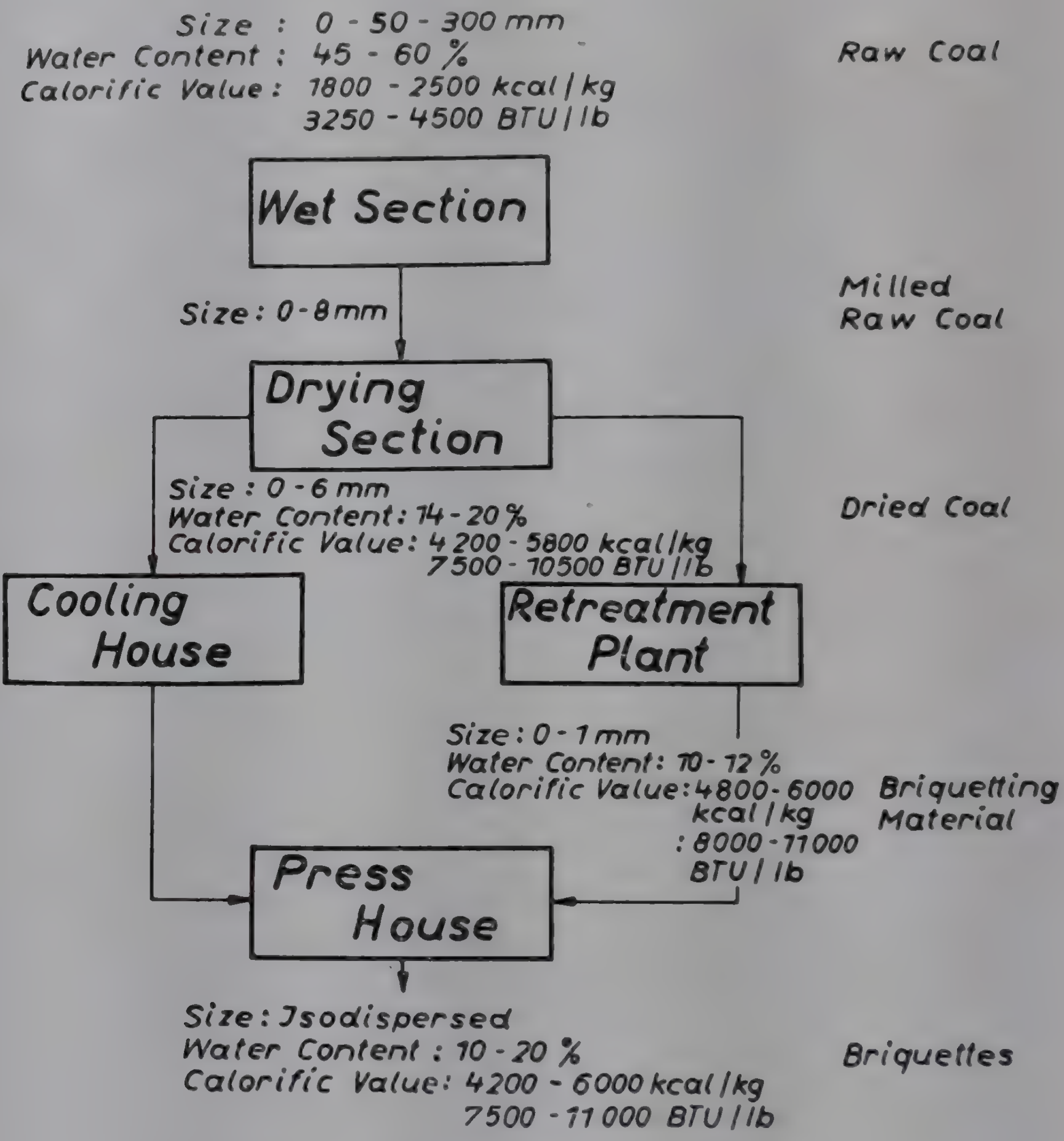

Size : 0 - 50 - 300 mm
Water Content : 45 - 60 %
Calorific Value : 1800 - 2500 kcal / kg
3250 - 4500 BTU / lb
Raw Coal
Wet Section
Size : 0-8mm
Milled Raw Coal
Drying Section
Size : 0 - 6 mm
Water Content : 14 - 20 %
Calorific Value : 4200 - 5800 kcal / kg
7500 - 10500 BTU / lb
Dried Coal
Cooling House
Retreatment Plant
Size : 0 - 1 mm
Water Content : 10 - 12 %
Calorific Value : 4800 - 6000 kcal / kg
: 8000 - 11000 BTU / lb
Briquetting Material
Press House
Size : Jsodispersed
Water Content : 10 - 20 %
Calorific Value : 4200 - 6000 kcal / kg
7500 - 11000 BTU / lb
Briquettes

FIG. 1—TECHNOLOGY OF BRIQUETTING

beginning of the nineteenth century. It could not provide a basis for a large and important sector of industry, until proper means of refining lignite could be found. Briquetting, one of the methods of improving the product, was the result of a demand for the improvement of the calorific value by removal of moisture by drying, and of the structural quality by pressing into lumps. The first lignite briquetting plant was brought into operation in Germany in 1858, about a hundred years ago[1].

The other method of refining, low temperature carbonization (l.t.c.) of the lignite, in fact, predates the briquetting process, and was first carried out in the forties of the last century. The l.t.c. process owes its existence to chemistry—more precisely to pharmacy, since pharmacists discovered that "black earth", which they were investigating, yielded significant quantities of tar and paraffins when dry distilled.

Each method of refining went its own way until the third decade of the present century, each serving its own particular functions. The briquetting process, carried out as shown in the process outline in Fig. 1, provided a product widely used in households and small-scale industry. The process outline shows the individual processing stages. The lignite, having a grain size of 0-50-300 mm., a moisture content of 45-60 per cent and a lower calorific value of 1800-2500 kcal./kg. is crushed to a grain size of 0-8 mm. in the wet section, thereby simultaneously causing some mixing and homogenization of the coal. The moisture content is then reduced to 14-20 per cent by drying, thus raising the calorific value to 4200-5800 kcal./kg. and reducing the grain size to 0-6 mm. Finally the dry coal is pressed at high pressure into briquettes, which leave the factory as an isodispersed product having high calorific value and good structural quality.

The l.t.c. process, on the other hand, consisted of putting crude lignite into indirectly-heated retorts, and aimed at producing valuable liquid products from the coal[2–4]. Since lignite has no caking qualities whatsoever, the coke produced in the process had a very small grain size and was considered a by-product of relatively limited usefulness. The maximum throughput of l.t.c. retorts using raw coal was very low so that further development of the process soon occurred. Firstly, a drying process for the coal was introduced prior to feeding it to the retort. This helped in improving the throughput capacity of the retort, as well as increasing the quantity of the coke "ballast".

The raw material position in the first world war forced a further increase in the oil production, which led to the introduction of gas generators for recovering the valuable coal products. In order to provide conditions of satisfactory gas flow, these gas generators were operated on lignite briquettes and in this way the two methods of refining the raw coal, which developed each in its own way for many decades combined for a common purpose. In the 1920's and 1930's, development of low temperature carbonizers from retort furnaces to internally-heated flush gas furnaces with high throughput led to an increased need for the application of briquettes to the l.t.c. process and provided impetus for the development of briquetting for l.t.c. The use of briquettes in l.t.c. gave this process a new lease of life, and even led to the production of high quality coke by high temperature coking of briquettes made by the extrusion pressing of fine grain coal[5].

It was recognized at an early stage that the further development of the l.t.c. process created not only the technical problems of carbonizer construction, but also the economic problem of the disposal of coke, both problems being of very great importance. The rubbly culm coke of low strength could not compete with pit coal products. For this reason numerous efforts to briquette the coke with the aid of a binder were made, but no economically feasible process was evolved. The production of coarse coke was only made possible by the use of briquettes in l.t.c. furnaces. The earlier use of briquettes of normal grain had led to the production of a coarser coke, although the amount of fines was still considerable. Systematic investigation of the factors involved in briquetting which influence the quality of coke produced in the 1930's, resulted in a much greater understanding of the relationship between briquettes quality and the coke properties[6-9]. It was found that the best coke is produced by using a coal of lowest possible moisture content (not greater than 10 per cent), and of a very small particle size (less than 1 mm.) for briquetting at high pressure.

Employing the results of these investigations, Herglotz developed a process for producing briquettes for l.t.c., using hard Bohemian lignite, and this has become known as the Lurgi-Krupp process[10,11]. In this process a crusher-drier heated by furnace gas is used for simultaneous crushing and drying, giving a very finely divided coal for briquetting. This material is then compressed into briquettes at a pressure of about 2000 kg./sq. cm., using a ring roll press. A considerable number of l.t.c. plants were operating on this principle in Germany up to the end of the last war, and produced a lumpy hard coke of excellent quality. All these plants were almost completely destroyed as a result of the war.

As a result of the investigations by several research workers it was found that l.t.c. process using extruded briquettes gave results similar to those obtained with briquettes produced on the ring roll press. Development work on the production of extruded briquettes from fines pushed ahead at the same time as the development of briquetting in the ring roll press[12-14]. Extrusion briquetting uses a material, dried in steam-heated tubular driers and then crushed, followed by a secondary drying stage if necessary. The process of pressing coal on extrusion presses after having been treated in furnace gas circulation driers is only carried out in one plant[15], it produces a lump coke of high quality. The production of extruded briquettes from fines has been highly perfected by extensive research work by Rammler and his co-workers in Central Germany since the end of the war[16-19].

The extrusion briquetting of coal fines has the advantage of having a relatively simple process technique, barely different in general from that of a normal briquetting plant. The difference between the two processes is shown in Fig. 1. The cooling house is replaced by a re-treatment plant, in which the dried coal is re-dried and re-crushed. The remainder of the plant hardly differs from the briquetting plants using normal size coal, and these can readily be changed over to finely crushed coal[20]. Fig. 2 shows the individual process stages for a plant producing extruded briquettes from fine-grained lignite. The raw coal is conveyed to the wet section from the raw coal bunker, and is then converted, by pre-classification, pre-crushing, fine crushing and fine screening, into a grain size of 0-6 mm. After an intermediate storage on the coal floor, the coal undergoes the main drying process, where its moisture content is reduced to about 10-11 per cent. The product is then screened into fractions of grain sizes 0-1 mm., 1-3 mm., and greater than 3 mm. This grading is required as the different

	Bunkering
Wet-Section	Pre-Classifging Pre-Crushing Main-Crushing Main-Screening
Drier-Section	Intermediate Bunkering Drying
Handling Dried Coal	Screening Re-Drying Crushing Screening
Press-Section	Intermediate Bunkering Pressing Process Transport to Carbonisation

FIG. 2—HANDLING STEPS OF FINE GRAIN BRIQUETTING

fractions have different moisture contents, namely 8-9, 10·11 and 14-16 per cent respectively. The first two fractions are already dried enough and the third coarse fraction must be re-dried to a moisture content of about 10 per cent. Thereafter the middle (1-3 mm.) and coarse (>3 mm.) fractions are crushed together in a screen hammer mill to a grain size of 0·1 mm. The crushed coal now ready for briquetting is fed to the briquetting press, through an intermediate storage. The finished briquettes are transported to the l.t.c. plant by means of a belt conveyor.

One might perhaps be led to conclude that extrusion briquetting represents the ultimate development of briquetting for l.t.c., and that this method has superseded the ring roll press. Undoubtedly such a conclusion would be premature and would give a distorted picture of the present situation. In fact it can be said that briquette production for l.t.c. has developed in two directions, each serving a particular field of application. The ring roll press is mainly used for the briquetting of older and harder lignites of poorer elasticity and for briquetting of coals that are more bituminous and difficult to briquette, and would not give a briquette of adequate quality by the extrusion. Extrusion, on the other hand, should be used for all normally briquettable young and earthy lignites which would create difficulties in the ring roll press due to their high elasticity. It is true that the ring roll press operates at a higher pressure and requires much less power than the extrusion press, but finely crushed, highly compressible coal may

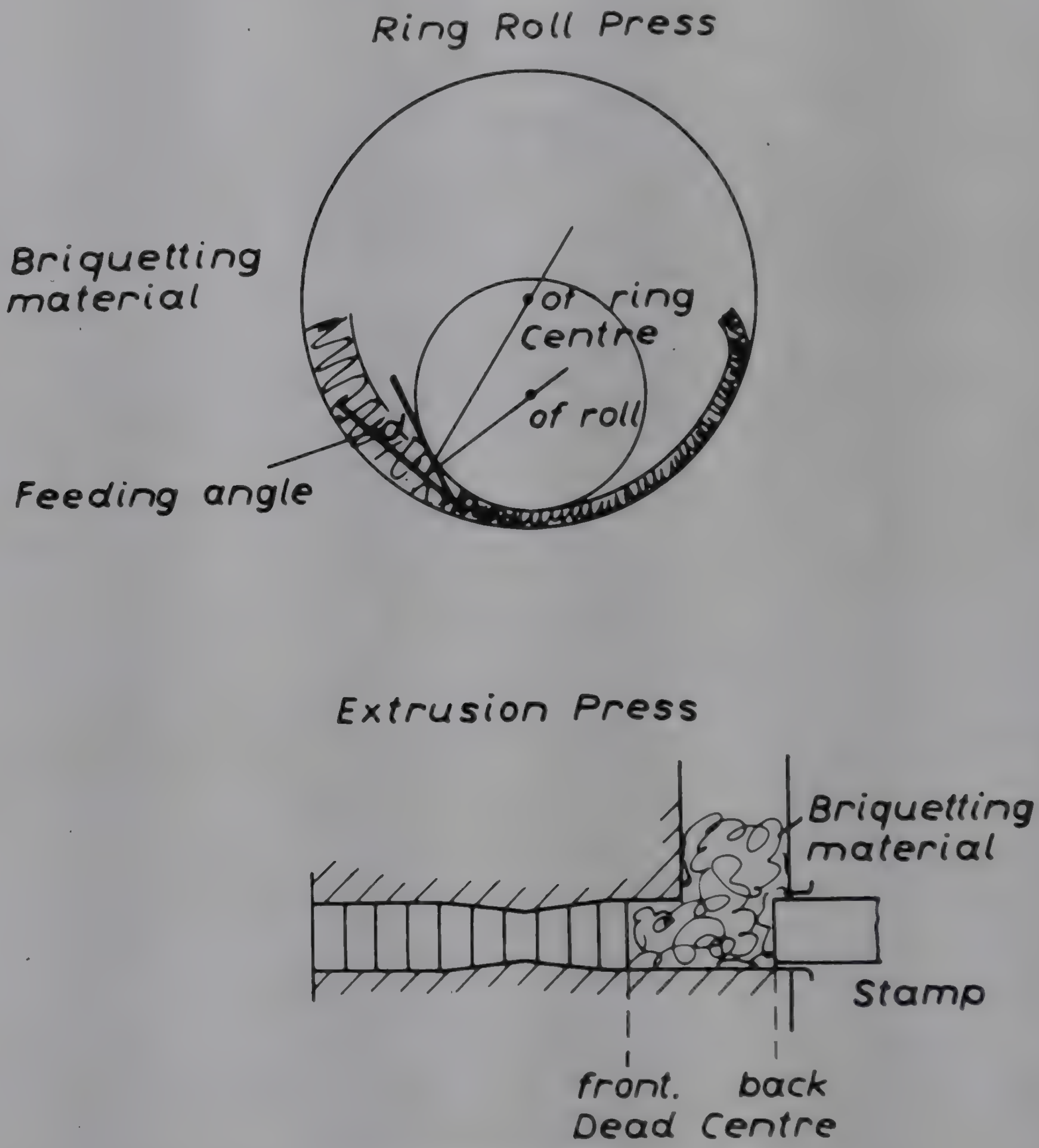

Ring Roll Press
Briquetting material
of ring
Centre
of roll
Feeding angle
Extrusion Press
Briquetting material
Stamp
front. back
Dead Centre

Fig. 3—Schematic diagram of press-processing

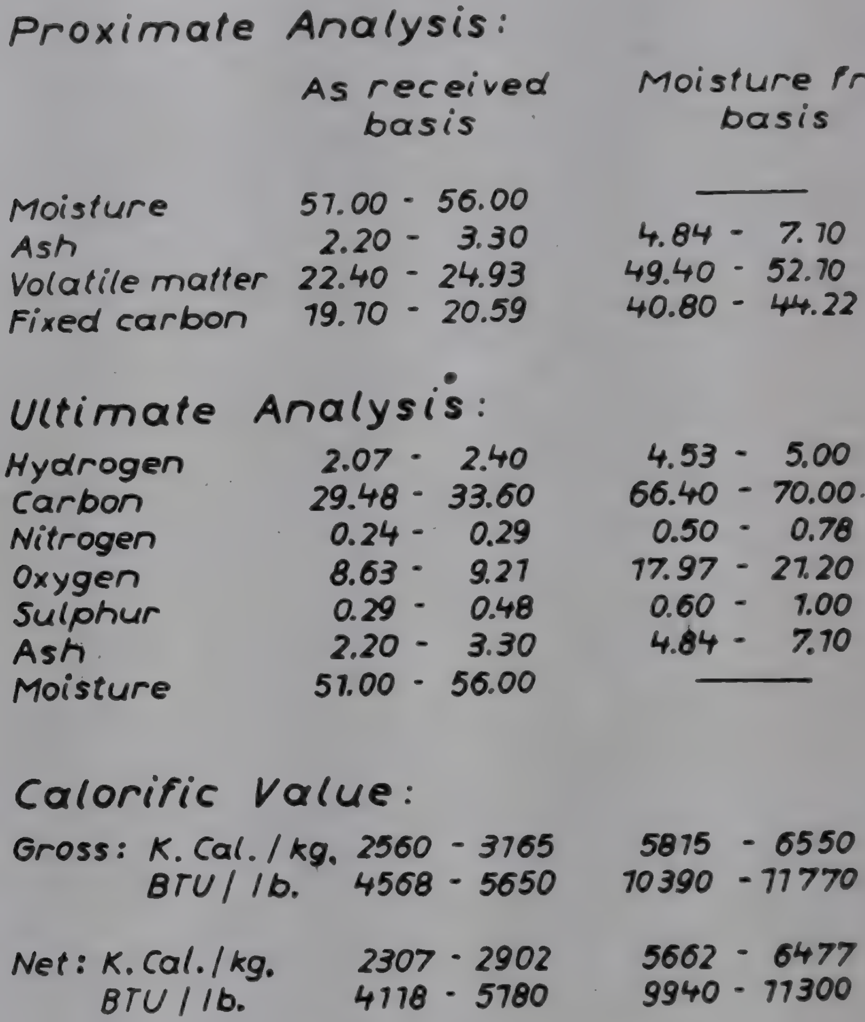
cause considerable feeding difficulties, due to the fact that feed conditions are fixed by the dimensions of the press as shown in Fig. 3. In the case of young coal the briquettes may be over-compressed, i.e. too high a pressure may lead to internal disintegration. Moreover, the pressure on the briquettes in the ring roll press is released suddenly, which may lead, in the case of great elastic deformation to such a powerful expansion of the briquette that splitters occur giving faulty briquettes which may burst along a smooth surface in a plane at right angles to the direction of pressing. The danger of this happening with hard non-elastic coal is only slight. In the extrusion press, on the other hand, the dimensions of the mould can be chosen to correspond to the expansion requirements of the briquettes, so that a controlled expansion, without formation of splitters, can be obtained. Splitter formation, even in the form of fine cracks, is particularly harmful in getting coke of good quality, as cleavages are then already in existence during the heating operation of the l.t.c.

As the emphasis of l.t.c. was changed from production of valuable liquid products and coke fines to production of lump coke for domestic, chemical industry or even metallurgical purposes, the source of raw materials also changed from coal with high bitumen content that was difficult to briquette to normal brown coal that was briquetted readily. This is best served by the extrusion press, which is therefore preferred to the ring roll press for the present purpose—the production of lump coke from normal coal. Seen in this perspective, the use of the ring roll press for brown coal, having its origin in the application to the types of coal that are difficult to briquette, may be considered a special development peculiar to the German l.t.c. industry, and one that would be difficult to apply to normal types of coal deposits available in other countries. Where a particularly difficult coal deposit is mined, that would produce unsatisfactory extruded briquettes, this special development, with its higher briquetting pressure, may be given special attention.

This situation was well appreciated by the authorities at the Neyveli Lignite Corporation, who therefore planned an extruded briquette factory for South Arcot Lignite and appointed Maschinenfabrik Buckau R. Wolf A. G., of West Germany, to undertake this task. The l.t.c. plant attached to this factory will be erected by Lurgi Gesellschaft für Wärmetechnik m.b.H., while electrical equipment will be supplied by Siemens-Schuckertwerke A. G.

SOUTH ARCOT LIGNITE

At the time of planning the South Arcot Lignite Project, it was not yet possible to obtain trial samples representative of the whole coal deposit at Neyveli, or at least for those areas likely to be min d during the next 10-20 years. Only at one point was a trial shaft sunk, giving several larger samples for trial purposes. Analyses of borehole samples from the remainder of the coalfield were available. These data are, however, not of much value in technical evaluation, as no method exists for deducing the ability to form briquettes and the coking properties from chemical analyses. Fig. 4 shows the proximate and ultimate analyses of South Arcot lignite, as provided by the Neyveli Lignite Corporation. The suppliers of the briquetting and coking plants were therefore faced with the difficult task of having to provide guaranteed performance without having precise information about the available raw material. The few available samples were extensively investigated at testing establishments in Germany, but we do not propose to reproduce the results in detail here, as the samples were not representative of the whole deposit. When the plant is put into operation, a further report on the results of practical operations will have to be compiled. Tests on the



Proximate Analysis:

	As received basis	Moisture free basis
Moisture	51.00 - 56.00	———
Ash	2.20 - 3.30	4.84 - 7.10
Volatile matter	22.40 - 24.93	49.40 - 52.70
Fixed carbon	19.70 - 20.59	40.80 - 44.22

Ultimate Analysis:

	As received basis	Moisture free basis
Hydrogen	2.07 - 2.40	4.53 - 5.00
Carbon	29.48 - 33.60	66.40 - 70.00
Nitrogen	0.24 - 0.29	0.50 - 0.78
Oxygen	8.63 - 9.21	17.97 - 21.20
Sulphur	0.29 - 0.48	0.60 - 1.00
Ash	2.20 - 3.30	4.84 - 7.10
Moisture	51.00 - 56.00	———

Calorific Value:

		As received basis	Moisture free basis
Gross:	K. Cal./kg.	2560 - 3165	5815 - 6550
	BTU/lb.	4568 - 5650	10390 - 11770
Net:	K. Cal./kg.	2307 - 2902	5662 - 6477
	BTU/lb.	4118 - 5180	9940 - 11300

FIG. 4—ANALYSIS OF SOUTH ARCOT LIGNITE

available samples have shown that South Arcot lignite has good briquetting qualities and gives briquettes with a crushing strength of well over 200 kg./sq. cm. The raw lignite is extremely soft and is in a disintegrated condition and can be easily reduced to a very fine grain size in hammer mills. The coke produced from the briquettes showed useful qualities. The ash content and composition varied sharply from sample to sample and also differed from the figures reported from India. From the ash analysis shown in Fig. 5 it can be seen that it is a lime-alumina ash of relatively high ash fusion temperature of about 1300°C. Since little is known so far of the properties of the lignite to be mined, it was necessary to make the briquetting plant as flexible as possible to meet with any change in the condition of the coal. Obviously the possibilities of adaptation are limited and cannot be carried out within a short time, while operating the plant. Continuous operation of the briquetting and carbonization plants can only be maintained if conditions of quality and quantity of the coal are maintained steady. It is an inevitable fact that briquette and coke quality depend on mining skill. It is above all necessary that the raw coal is recovered from the pit and fed to the plant in homogeneous mixture, for it is not

Ash Analysis % :

	As received basis
SiO_2	11.99 - 27.46
Al_2O_3	14.52 - 29.16
Fe_2O_3	2.80 - 11.00
TiO_2	traces
CaO	22.93 - 40.54
MgO	2.80 - 8.18
SO_3	15.90 - 25.80
Alkalis	0.48 - 0.92
Phosphate	traces 0.10

Ash fusion Temperature :

	Reducing atmosphere	Oxidising atmosphere
Softening stage	1180 - 1320	1300 - 1358
Melting stage	1270 - 1345	1400 - 1405
Flow stage	1385 - 1460	1440 - 1463
Fusion range	1180 - 1460	1300 - 1463

FIG. 5—ANALYSIS OF SOUTH ARCOT LIGNITE

possible to correct mistakes made in mining during the processing operations. For these reasons the operation of decentralized coal mining using small dredgers at different points of the stope being mined has been shown to be advantageous. In this way coal is recovered from the whole height of the slope, with the dredger moving along a certain section of the slope. This ensures uniform production and mixing of coals differing from one position to another. It has been found that close co-operation of the management of the mine and of the refining plant in efforts to produce high quality material has been of great assistance. In planning the working of the mine, the viewpoint of the refiner should be given due consideration, as he must know the characteristics of the various types of coal for his continuous investigations.

THE BRIQUETTING FACTORY

Neyveli is situated 233 km. south of Madras and is 32 km. from the sea. The coalfield covers an area of about 200 sq. km. A fertilizer plant and a power station, forming part of the project are also to be erected on the site, in addition to the briquetting and carbonizing plants. The South Arcot lignite will therefore be used for gasification, for producing steam and power, in addition to its being used in the briquetting and coking processes. Lignite from the mine is brought to the raw coal bunker by means of belt conveyors. From here it is transported by means of a conveyor bridge to the wet section. The processed raw lignite is then transported by conveyor bridges to the main building of the factory, where the drier and pressing sections are housed. The retreatment plants are constructed as wings at right angles to the main building. A conveyor bridge extends across the launder yard and carries the briquette collecting belt. From here the briquettes are conveyed by means of a rising conveyor bridge to the l.t.c. plant.

All buildings for the briquetting plant will be constructed on a steel skeleton construction basis, with self-supporting solid outer walls (Fig. 6). The intermediate ceilings are to be made of grid iron or concrete according to particular requirements. The roofing is of light-weight precast concrete panels. The conveyor bridges are of open construction and are protected against the wind by medium-height Eternit, which is also used for the roofing of the bridge.

The plant is designed for a maximum production of 2660 metric tons/day of finest grain briquettes containing 10 ± 1 per cent moisture. This requires a raw coal input of about 5600 metric tons/day, containing approximately 56 per cent moisture. Since the coal bunker has a storage capacity of 3000 metric tons, sufficient for twelve hours' production, theoretically there will be a twice-daily turnover of the bunker contents. This facilitates a certain amount of mixing of the lignite and small variations of feed with regard to quantity and quality can therefore be evened out.

The raw lignite feed is first crushed in a blade crusher, reducing it to a grain size of 0-250 mm. The method of operation of the blade crusher can easily be deduced from Fig. 7. Fig. 8 shows a view of this crusher. The broken coal is delivered to the bunker, which is in the form of a slot bunker above ground, evenly over its whole length by a reversible belt conveyor. At its lower end the bunker is open over its entire length, so that the lignite can fall freely on to a table placed below (Fig. 9). The breadth of the table and the size of the slot formed between the table and the bunker outlet are such that the lignite remains on the table and cannot run off. It is continuously removed from the stripper table by a bunker discharge wagon, and is transferred to a belt conveyor. With the aid of a gear the quantity of lignite can be altered at will to any amount between 100 and 400 tons/hr, and the amount of lignite passing to the wet section can be registered by using belt weighing machine incorporated into the conveyor bridge.

The flow diagram for the wet section is shown in Fig. 10. A horizontal process, having the individual units of the different process stages arranged in parallel, is used. This arrangement is preferable to the vertical system of wet processing because, in case of failure of one machine, only one process stage is affected, while all the units of the other stages continue operating normally[21].

The lignite having a grain size of 0-250 mm. is first fed to a toothed

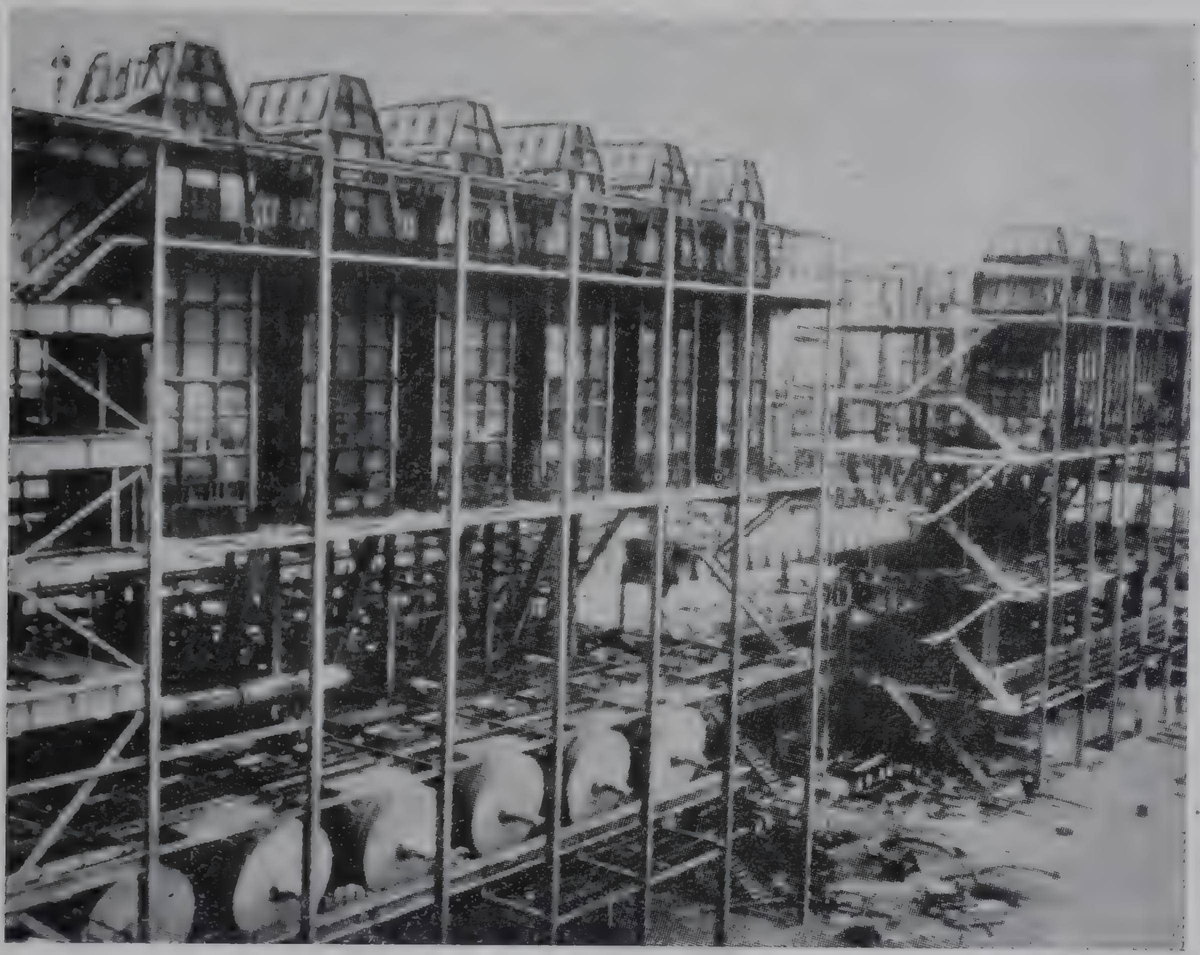


Fig. 6—Steel framework

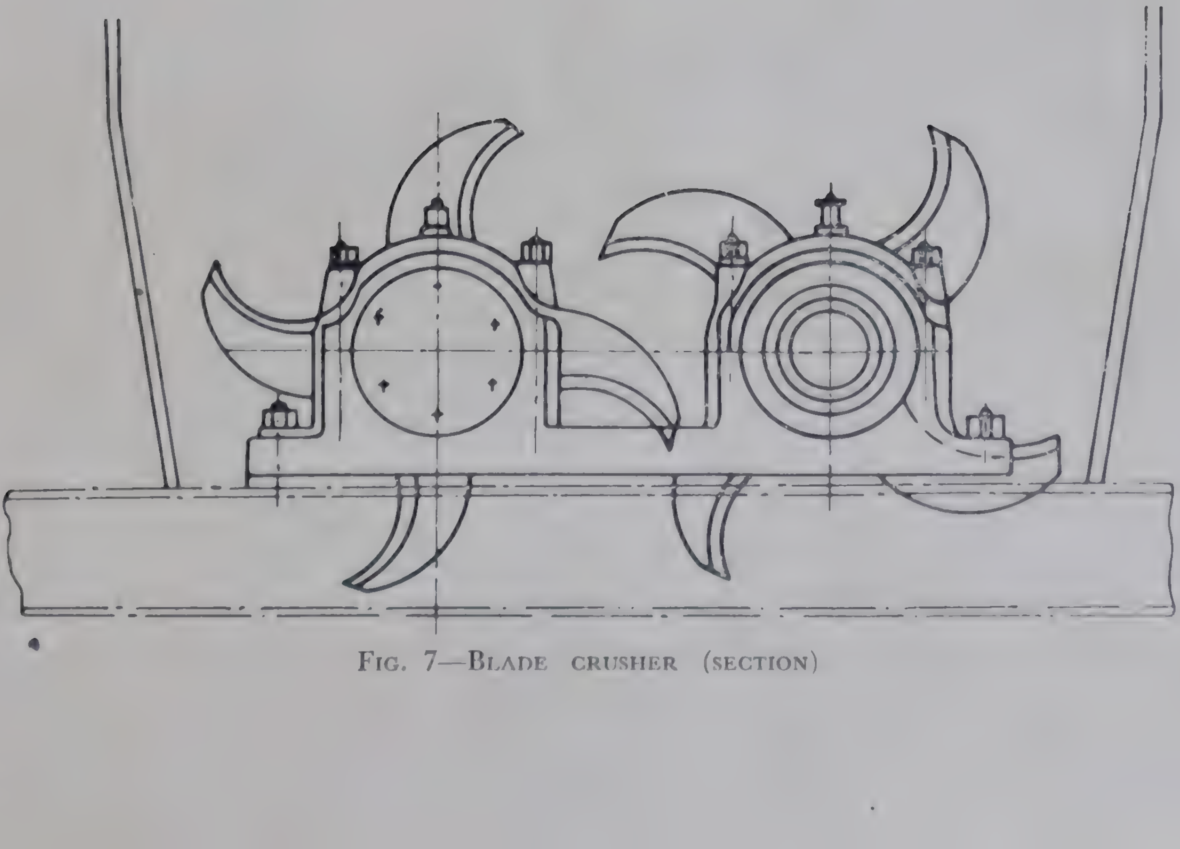


Fig. 7—Blade crusher (section)

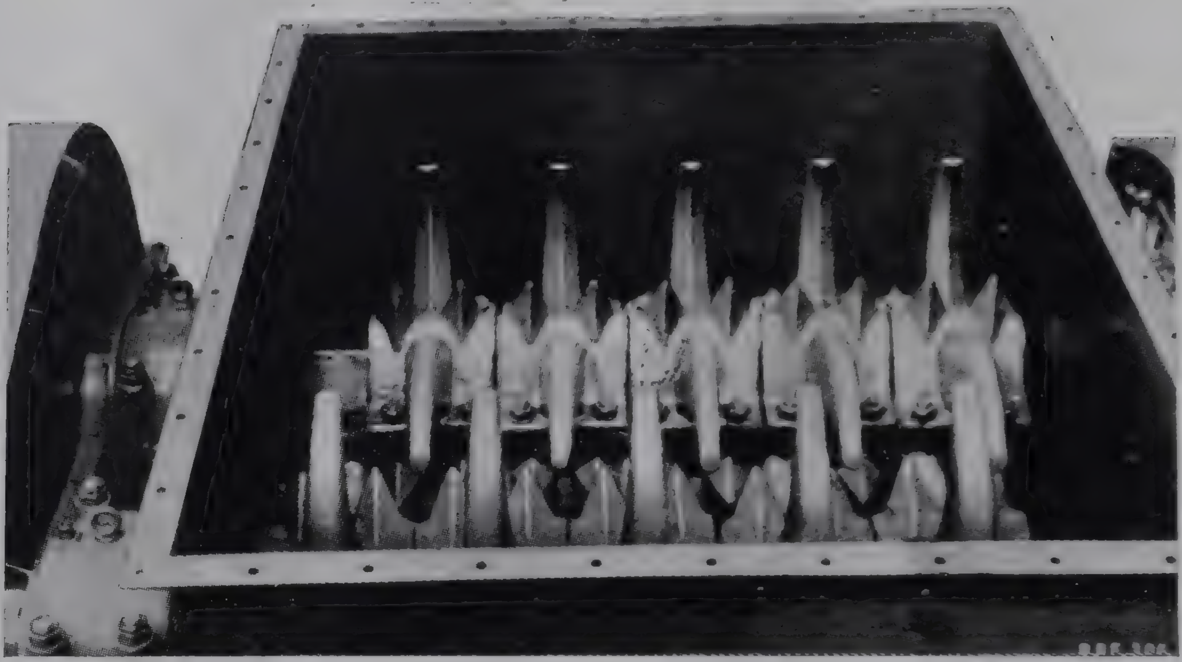


FIG. 8—BLADE CRUSHER

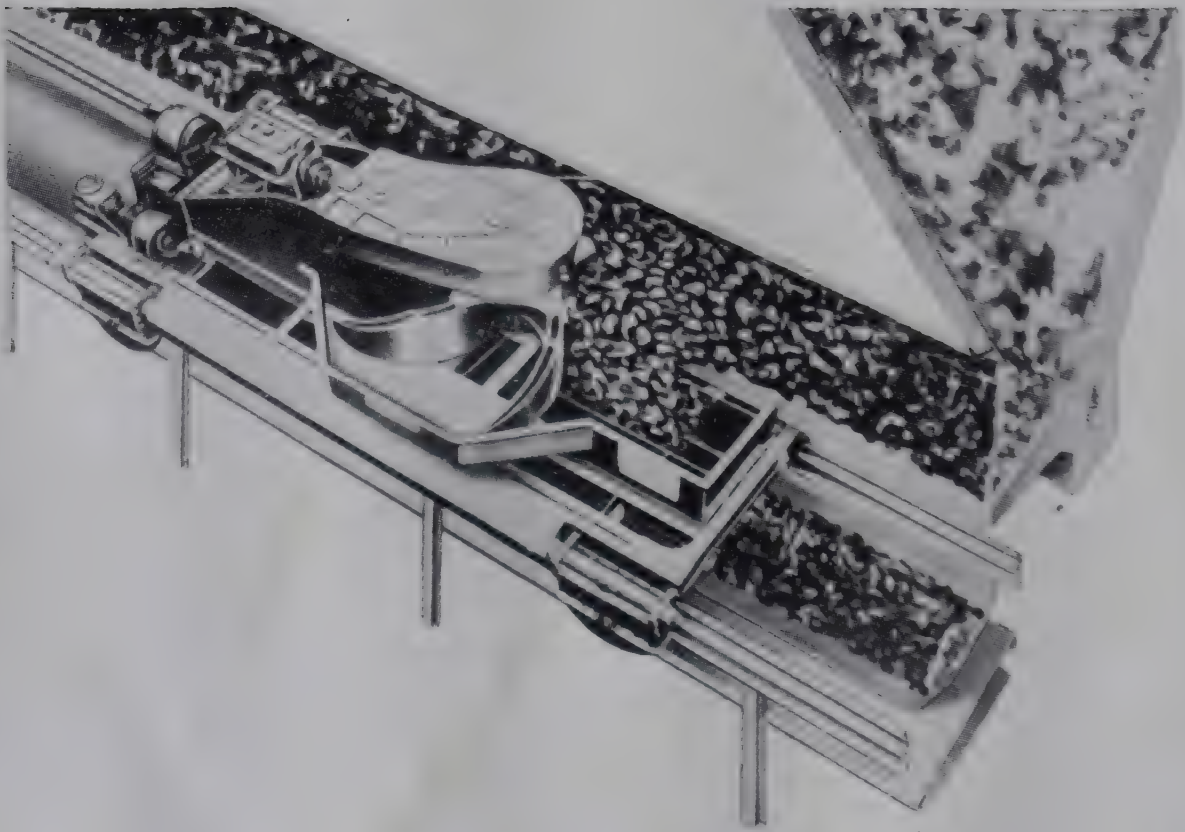


FIG. 9—BUNKER WITH EVACUATING WAGON

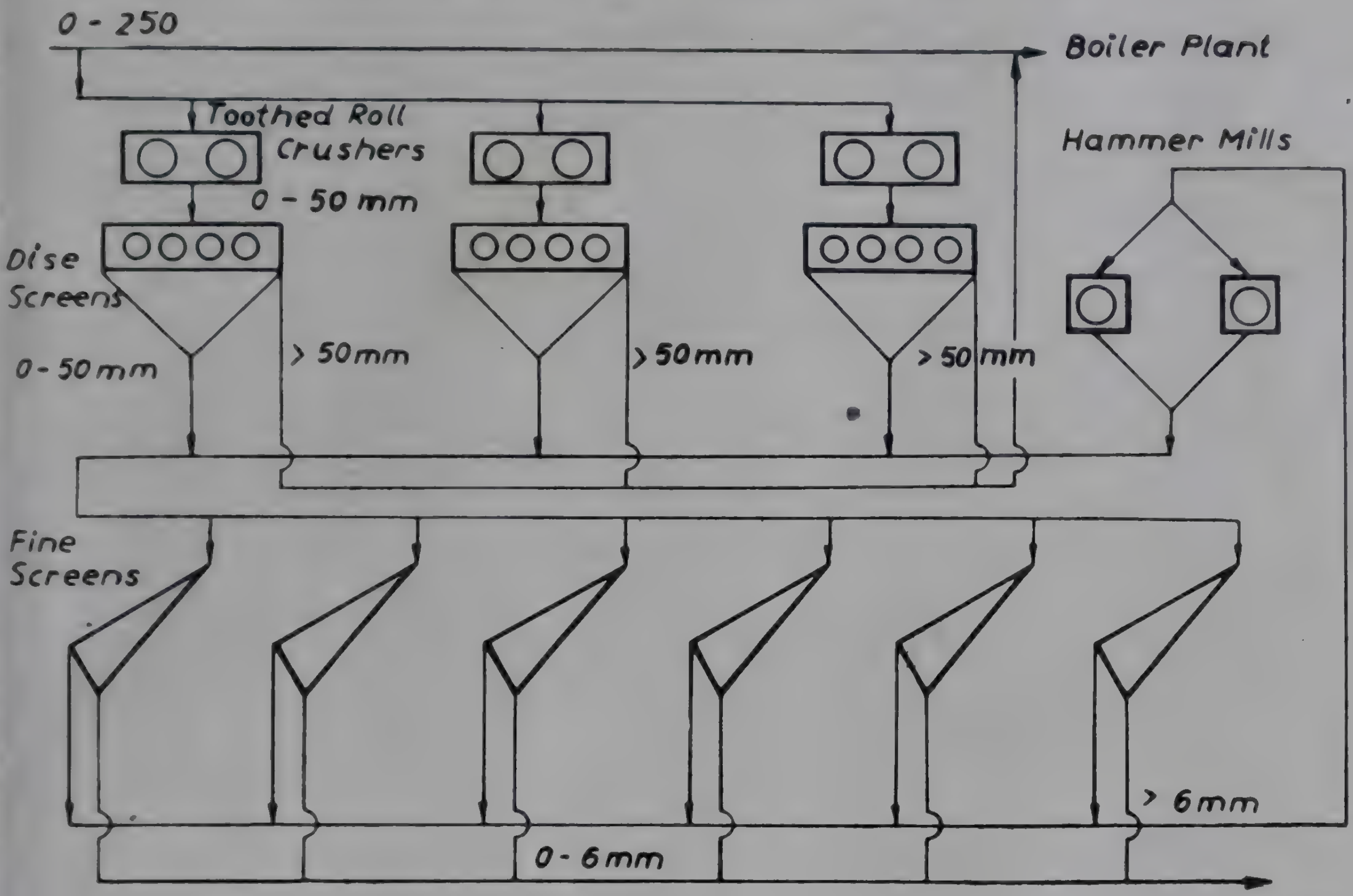

0 - 250
Boiler Plant
Toothed Roll Crushers
Hammer Mills
0 - 50 mm
Disc Screens
0-50mm
> 50mm
> 50mm
> 50 mm
Fine Screens
> 6mm
0-6mm

FIG. 10—FLOW SHEET OF WET SECTION

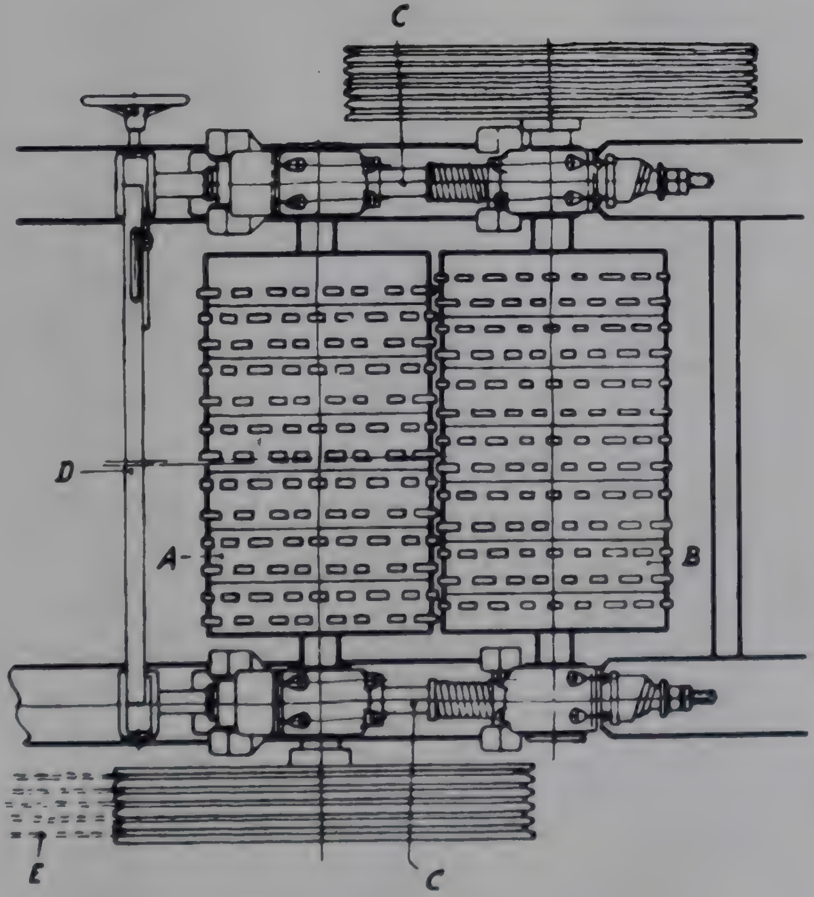


FIG. 11—TOOTHED ROLL CRUSHER (SECTION)

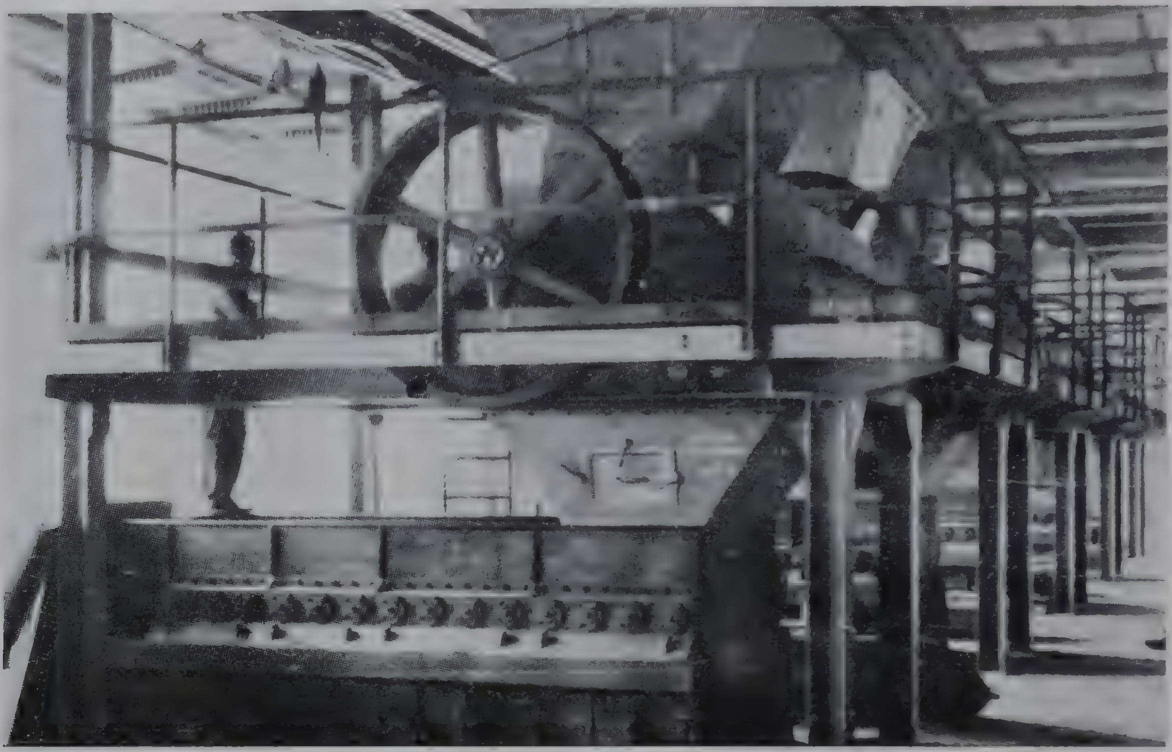


Fig. 12—Toothed roll crusher and disc screen

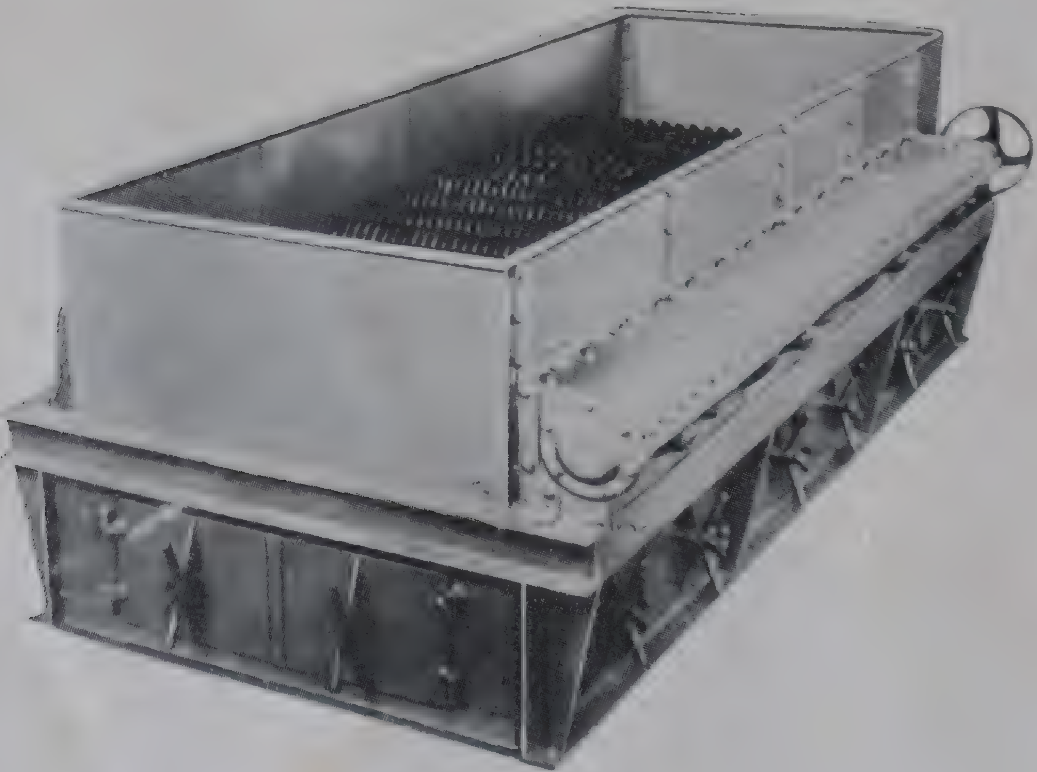


Fig. 13—Disc screen

roll crusher, which as a first step reduces the grain size to 0-50 mm. (Fig. 11). A disc screen is fitted under the roller crusher (Figs. 12 & 13), and here the pre-crushed coal is classified at a size of 50 mm. in order to separate the hard, coarse lumps or longitudinally breaking wood components. These are sent to the boiler as overflow after passing through a hammer mill. It is also possible to add this material to the lignite to be briquetted, should the boiler bunker be filled or when a greater demand for briquetted lignite occurs. The material passing through the disc screen passes to the fine screens (Fig. 14), which operate in a hammer mill circuit. This arrangement has the advantage of mixing the fine material on these screens with the coarser 0-50 mm. size from the disc screen, thus loosening the finer material and ensuring effective screening at this stage. The material passing through the fine screens (grain size 0-8 mm.) is conveyed as briquetting feed to the drying section, through a belt weighing machine, while the coarse fraction of 8-50 mm. passes to screenless hammer mills and is then recirculated to the screens (Fig. 15). Double shaker screens with automatic screen cleaners are used as fine screens, and have a screening surface of 18 sq. m. and can take a load of 150 tons/hr. The hammer mills have a cross-section of the rotor of 2.5 sq. m. for a throughput of 200 tons/hr.

All units in the wet section are controlled from a central control panel, which permits easy control of the plant. The conveyors and preparation units are interlocked in the direction of material flow, so that interruptions causing serious damage to belt conveyors are avoided.

The drier and press section, which follow the wet section, are divided into two equal divisions and can be operated independently of one another, so that the processed lignite can be divided into two streams. Each division of the drying section consists of 6 driers with a heating surface of 2200 sq.m. (Figs. 16 & 17). Each drier contains 876 tubes of 108 mm. diam. and is hexagonally divided, being equipped with spiral retarders and Buckau screen roll retarders (Fig. 18). In this way the lignite is dried more evenly, as the fines of diameter below 3 mm. mostly find their way into the interior of the screen roll retarders, where less drying occurs. The moist coarse material, on the other hand, is carefully re-crushed, and dried intensively along the fresh faces of fracture, thus producing only a small moisture difference. The driers are operated with slightly superheated steam at 180°C. and 3·8 kg./sq. cm. pressure.

The drier journals run in antifriction bearings provided with central circulating oil lubrication in each division.

Slide channels are fitted under each tube row at the discharge end of the drier and these discharge the lignite with proper care and without creating excessive dust (Fig. 19). From the discharge housing the dried material passes to the drier collecting conveyor by means of two cell wheels, which also form an explosion seal. A vertical Redler conveyor transports the lignite from the drier collecting conveyor to the retreatment plant.

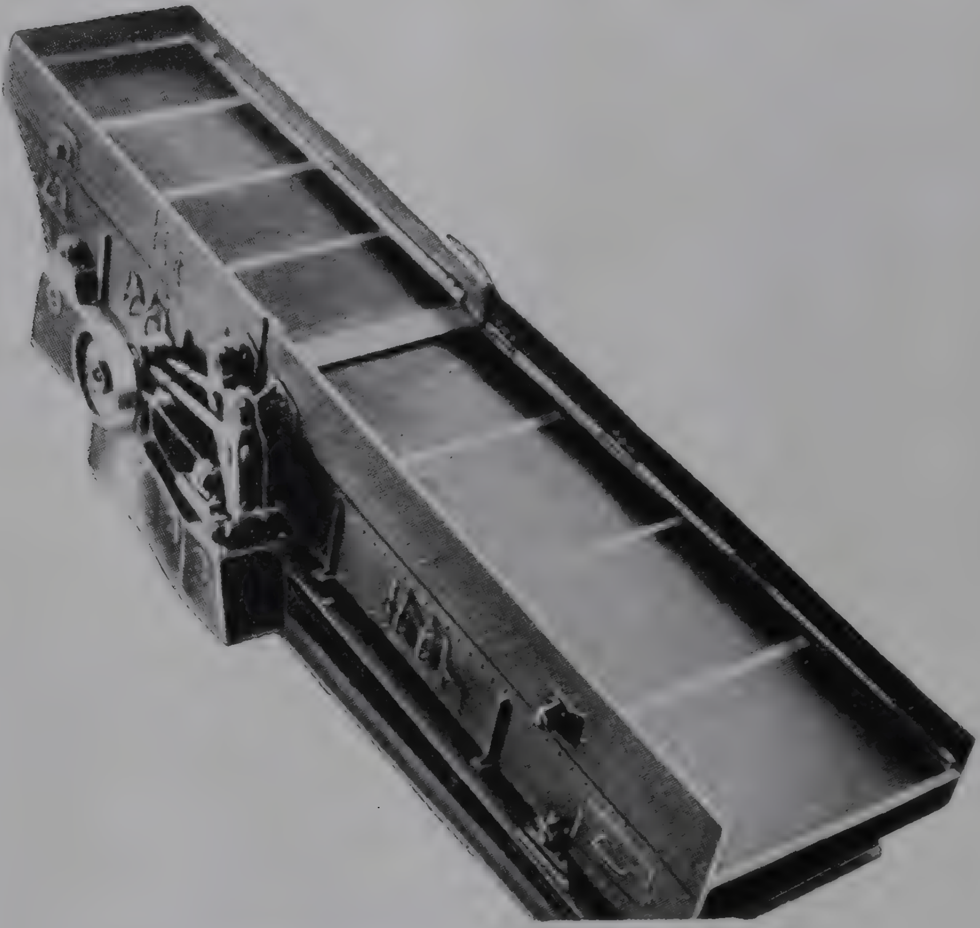


Fig. 14—Double shaker screen (without cleaners)

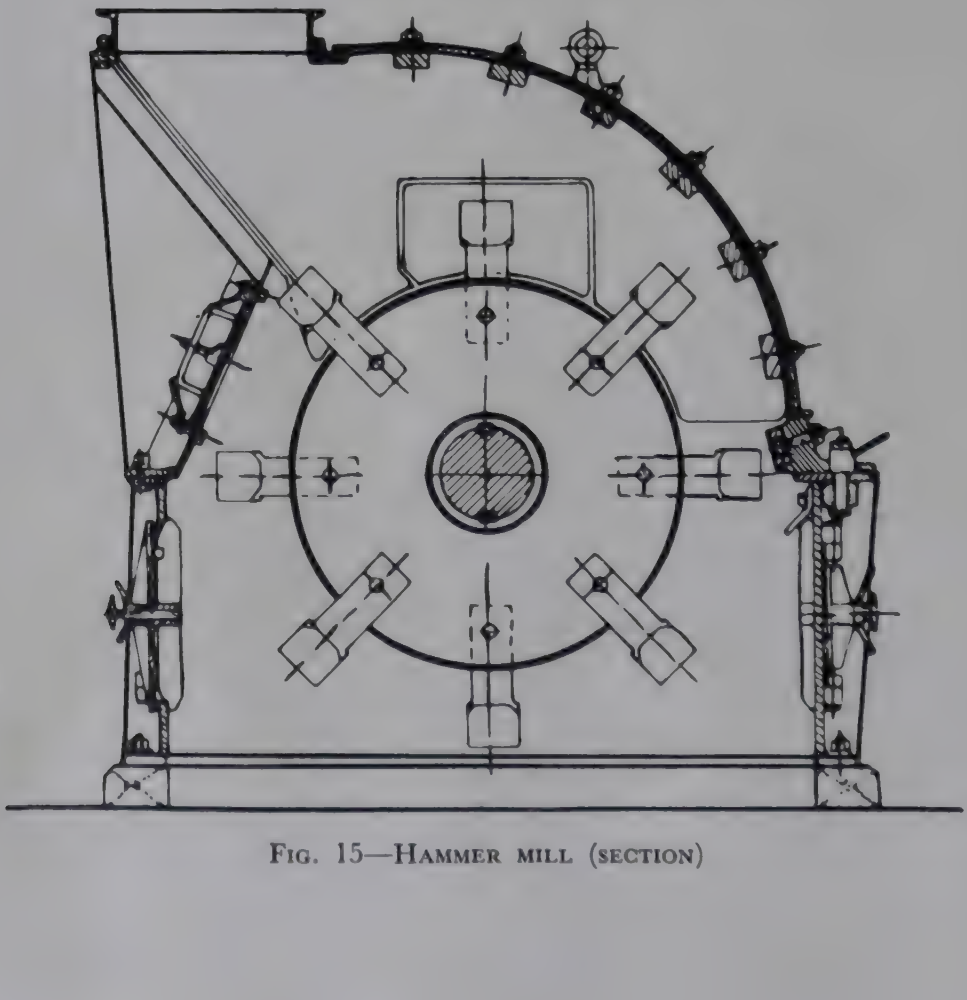


Fig. 15—Hammer mill (section)

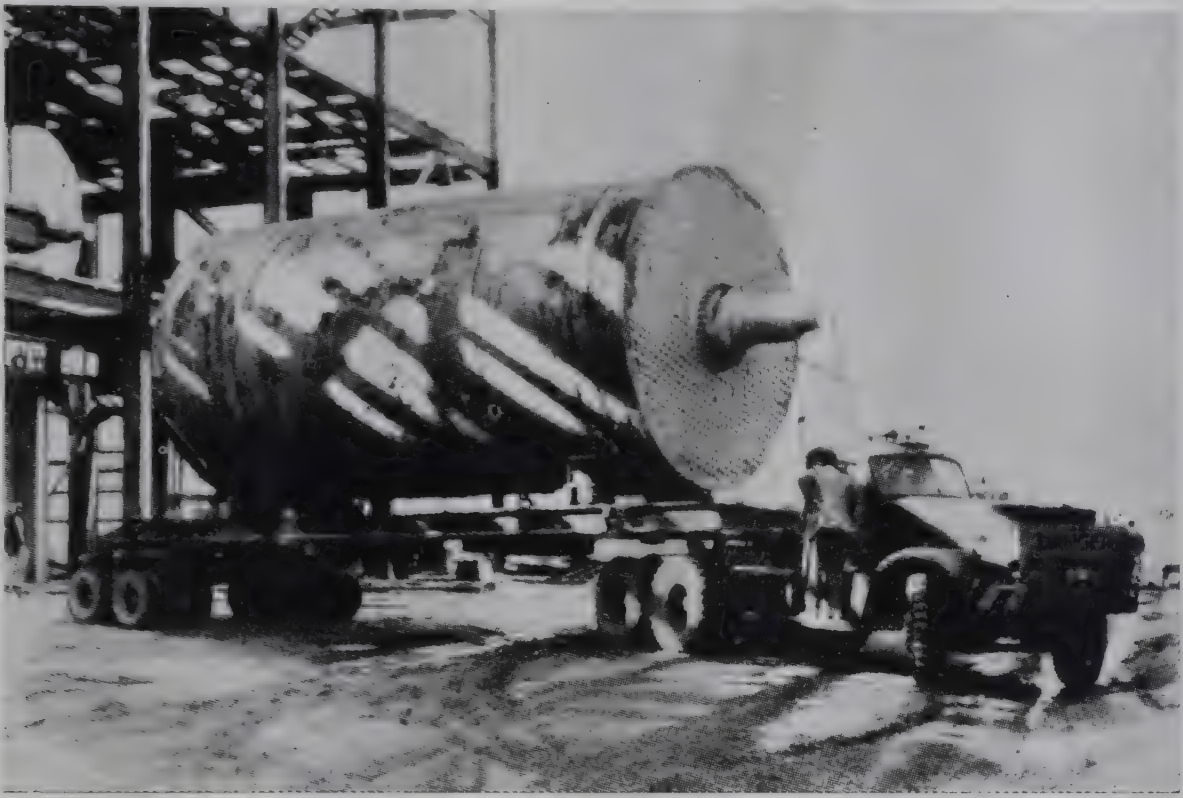


FIG. 16—TUBULAR DRIER 2220 sq.m. (TOTAL VIEW)

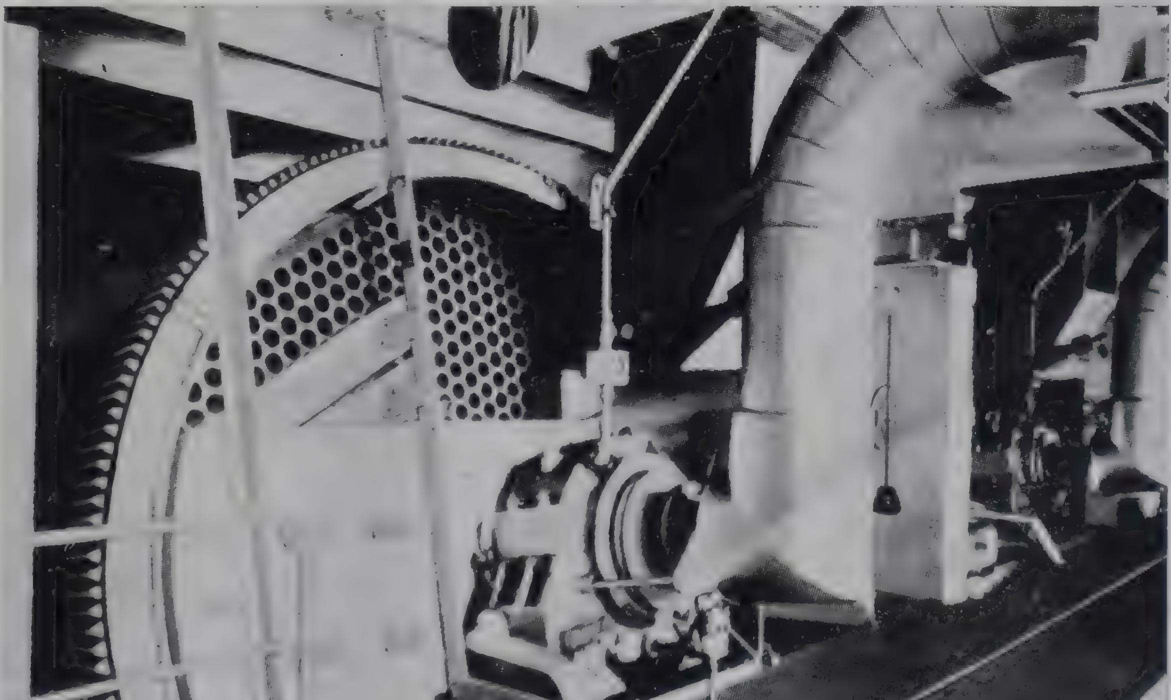


FIG. 17—TUBULAR DRIER

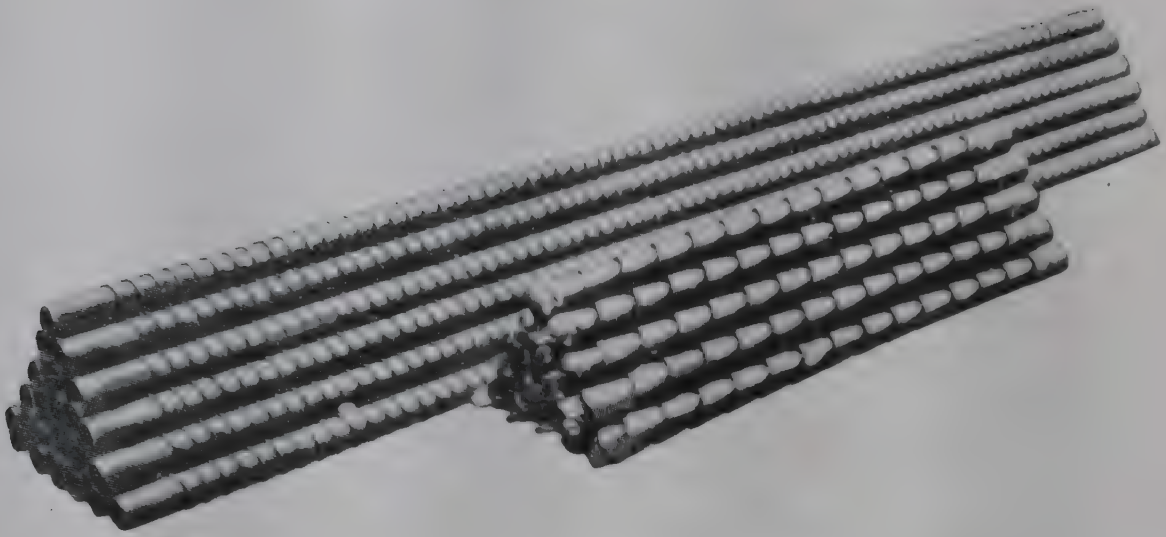


FIG. 18—SCREEN ROLL RETARDERS

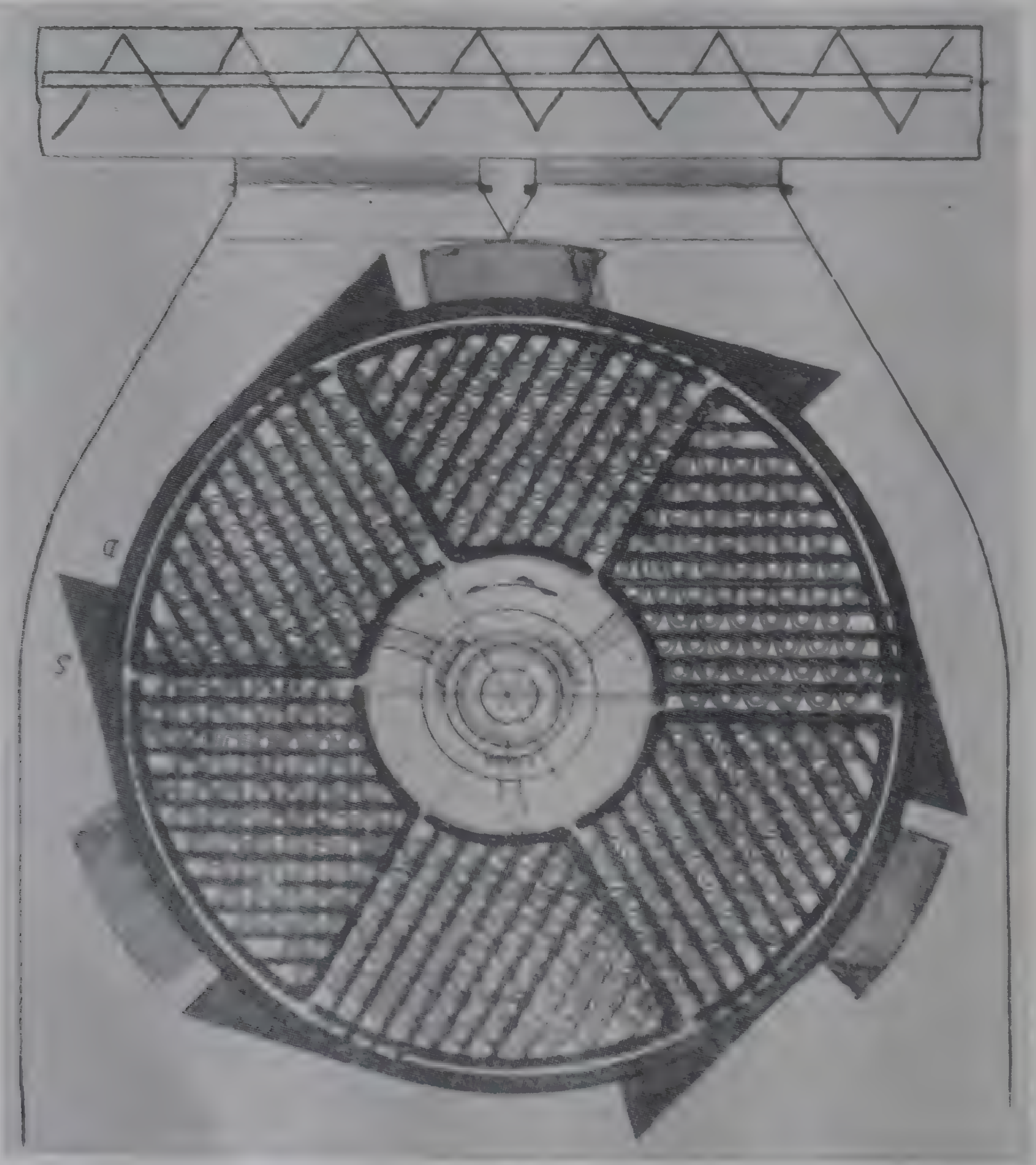


FIG. 19—TUBULAR DRIER, STRIP DISCHARGE DEVICE

Each drier is driven by an a.c. commutator motor, which permits an infinitely variable speed control. Alteration of the speed of each drier occurs automatically to maintain a constant moisture content in dried lignite. The control impulse is derived from an automatic moisture analyser working on the capacitative principle. At the same time a strip recorder is used, so that the moisture content of each drier is set according to an absolute reading and the fluctuation.

Each drier stack has an electrostatic precipitator incorporated to remove dust from the vapours. Selenium rectifiers are used to rectify the high tension current and these operate without any interruption or control. In order to maintain a constant degree of dust elimination, an automatic current regulation is provided for the electrostatic precipitators, thus achieving a constant electrical field. The current threshold is so chosen that breakdown voltages are definitely eliminated. In order to avoid breakdown voltages with subsequent fires, the precipitator has a cut-out system which operates when disturbances occur in the raw feed to the drier. Since, in that case, the steam consumption is reduced, a steam consumption meter is installed as a signal and impulse generator.

De-dusting of the conveyors is carried out by a mechanical de-dusting plant using cyclones and wet separators.

The retreatment plant is the characteristic feature of a factory producing briquettes for l.t.c. from finest grained coal. In this plant the lignite to be briquetted is given the desired properties in so far as grain structure and moisture content are concerned. The flow diagram of the retreatment plant is shown in Fig. 20. The dried lignite comes from the drier section in a size range 0-6 mm. and is fed to a screen chain conveyor. This has two screens of 2·3 mm. and 1·3 mm. mesh size and the lignite is separated into fractions of size ranges 0-2 mm., 2-3 mm., and 3-6 mm. The 0-2 mm. fraction passes to fine screening, while the middle fraction passes directly to the mills. The moist 3-6 mm. coarse fraction is redried to a moisture content of 10-11 per cent and then milled in hammer mills. These operate in circuit with the fine screens so that no material that has not passed through the fine screen can reach the briquetting plant. The screen chain conveyor which produces a separation at 2 mm. is provided with two decks in the interests of flexibility of the plant as mentioned earlier and to lessen the load on the fine screens. It is possible without any rebuilding of the plant to eliminate the 1·3 mm. screen and feed the fine screens with a material of 0-3 mm. At the same time this material could also be fed directly to the hammer mills. The size range of the lignite to be briquetted can be varied by an alteration of this fraction, since any desired amount of fines of size range 0-1 mm. can then be subjected to an additional crushing. On the flow sheet this possibility has been indicated by the bracketed grain sizes.

In each division the fine screens consist of eight horizontal rotary screens, each having a surface area of 2·5 sq. m. and fitted with 1 mm.

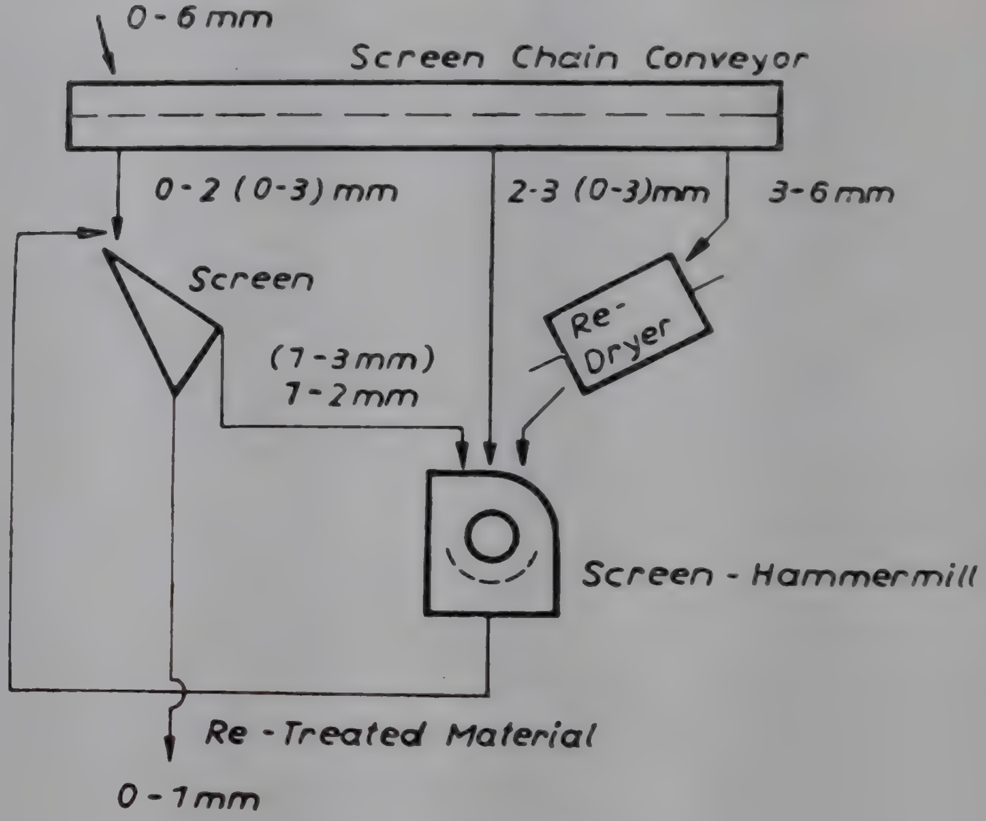

0-6 mm
Screen Chain Conveyor
0-2 (0-3) mm
2-3 (0-3)mm
3-6mm
Screen
Re-Dryer
(1-3mm)
1-2mm
Screen - Hammermill
Re-Treated Material
0-1mm

Fig. 20—Flowsheet of retreatment plant

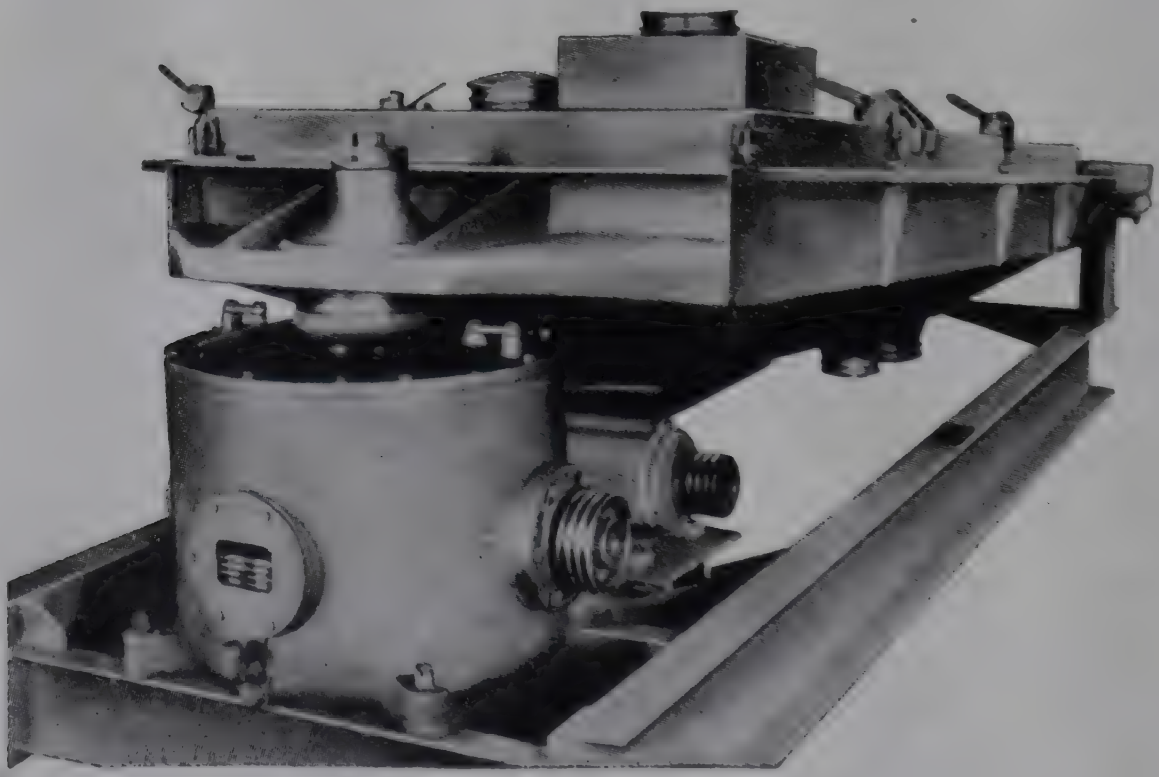


Fig. 21—Horizontal rotary screen

square mesh (Fig. 21). The screens are equipped for automatic cleaning by means of sectionally divided double bottoms filled with rubber balls. The screens are completely enclosed to avoid dust formation. The even distribution of lignite over the various screens is ensured by the use of quantity-controlled cells wheels. Each division has four screen hammer mills for re-milling purposes, with a rotor cross-section of 1 sq. m. The re-drying of the moist coarse lignite is carried out in a re-drier fitted with 252 tubes having a heating surface of 527 sq. m. Clubs are fitted to obtain a certain amount of re-crushing so that uniform drying can take place. The drier is heated with saturated steam at 0·1-3 kg./sq. cm. pressure, and the steam is controlled by a pressure reducing valve and a steam cooler. The lignite is removed from the discharge housing by means of a closed chain conveyor which, at the same time, provides a seal in case of an explosion.

As in the main drying section, regulation of the moisture content is effected by the aid of the speed of the drier which is varied by a commutator motor controlled by an automatic moisture analyser.

Since the re-drier only handles coarse lignite, dust formation is only slight. Therefore dust removal from the vapours is carried out by a mechanical de-dusting plant in which dry cyclones are used, followed by a further cleaning with wet separators.

The fine lignite, now fully prepared for pressing, is transported to the press section by a vertical conveyor.

The press section of the factory is equipped with 13 double twin presses having 10 in. jaws, which are installed in two divisions containing 6 and 7 units respectively. The lignite to be briquetted, coming from the retreatment plants, is fed to the presses by means of a distributing screw conveyor. In order to ensure that all the presses have adequate supplies of lignite, this conveyor is always overfilled, the excess being returned to a return feed bunker by a special conveyor. This bunker is emptied continuously. A jalousie vertical chain conveyor is used to fill the bunker in order to avoid dust formation. The briquette presses are constructed as crank mechanism extrusion presses (Figs. 22 & 23). They are driven by a flywheel situated midway between the two halves of the twin press. The flywheel is driven by a motor mounted in the basement. All presses in any one section are connected to a central oil circulating lubrication plant fitted with cooling and filtration equipment. A chrome leather plastic compound belt of high elasticity is used as a drive. The motor is of a controlled speed commutator type taking a 540 kW load and imparting a speed of 58-78 r.p.m. to the press. The motor is protected by a current controller having an acoustic signal device fitted in the cooling air duct, and in this way the presses would be stopped in the case of failure of the cooling air fans. In addition, the motor has an overheating protection device which cuts off the power in case of exceeding a predetermined temperature in the windings.

Lignite is fed to the presses via small hoppers having steeply-inclined

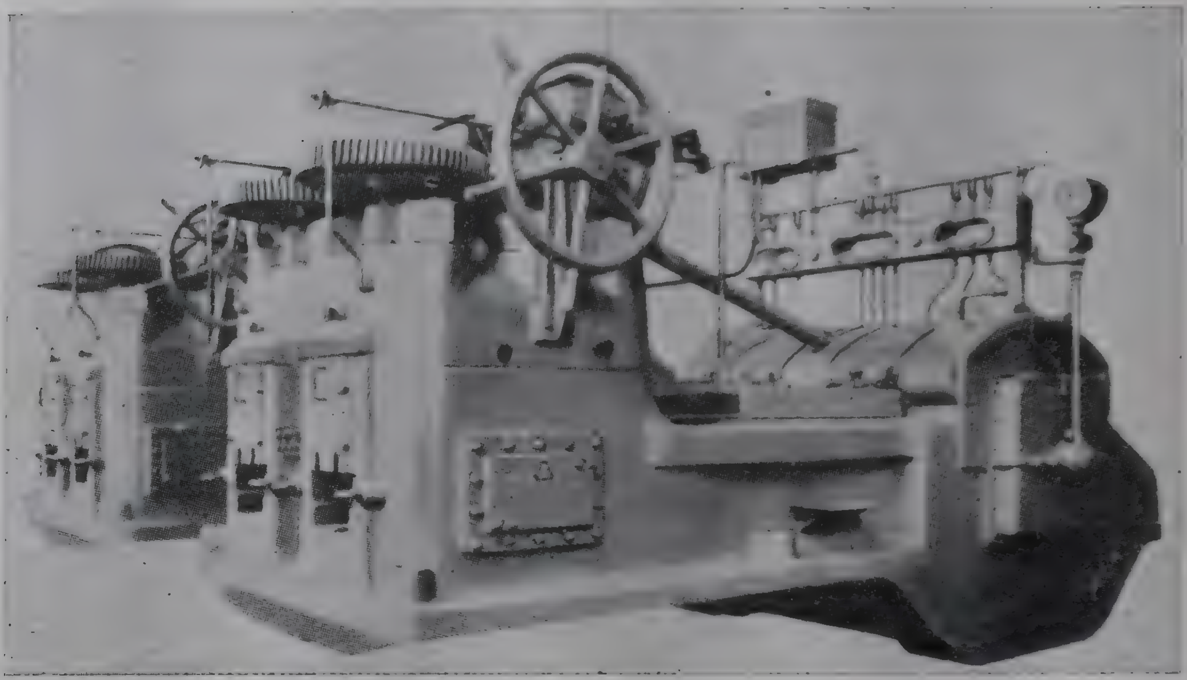


FIG. 22—DOUBLE-TWIN EXTRUSION PRESS 10″ (WITHOUT FLY WHEEL)

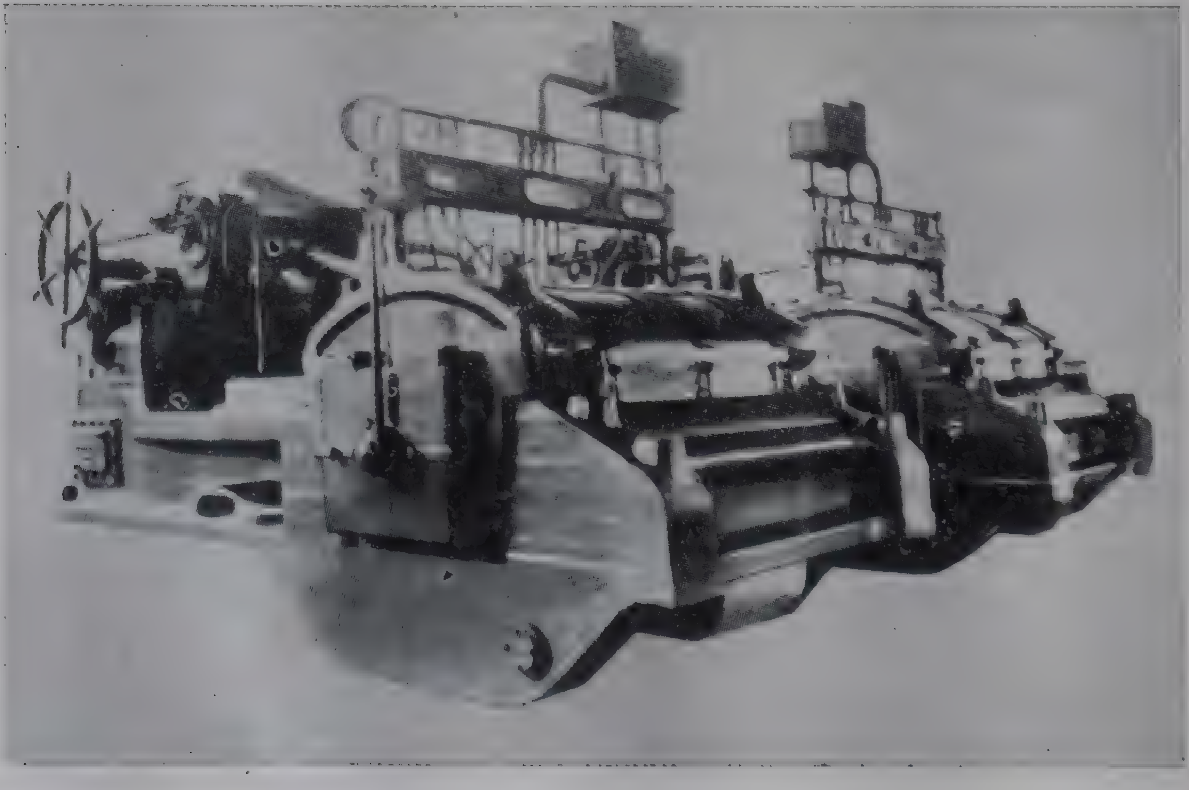


FIG. 23—DOUBLE-TWIN EXTRUSION PRESS 10″

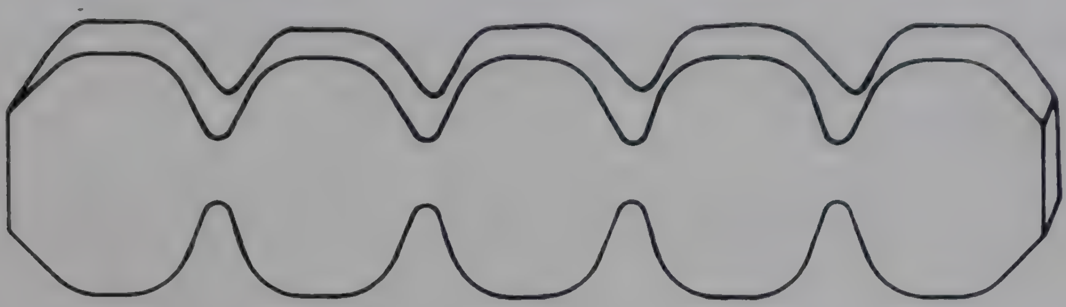


FIG. 24—BRIQUETTE SHAPE

walls to give a frictionless continuous feed. The lignite passes from hoppers to feed rolls and then to the filler shaft of the press. The feed rolls are shaft-driven directly from the crankshaft and the lignite feed is thus varied automatically with the speed of the press.

The presses are fitted with a five-part 10 in. industrial die, as shown in Fig. 24. For a briquette thickness of 40 mm. a briquette row will weigh approximately 650 g. A crane is provided to ease the form setting and with the aid of this crane the form hooks can be inserted into the mould channel without any difficulty. The removal of lignite adhering to the stamp is effected by stamp de-dusting and for this purpose each stamp has a cyclone fitted directly to the press. The dry separated lignite is immediately returned to the press. The discharged air from the cyclone is withdrawn centrally and re-cleaned in a wet separator.

The briquettes are moved via launders of 80 m. length to the briquette collecting belt conveyor and are transported to the carbonization plant from there after fines caused by abrasion have been separated on a roll grate.

The worn mould tools are ground in a form grinding plant equipped with three combined form stamp grinding machines. Grinding to the correct mould tool dimensions is obtained automatically by profile grinding discs. The grinding discs are trimmed in a special device so that an unchanging mould tool profile is ensured.

All auxiliary plants required for the operation of a briquetting plant, such as workshops, laboratories, electrical distribution stations, etc. are constructed in accordance with the most modern ideas. It is, however, beyond the scope of this review to detail these installations, as this review was intended only to provide a general survey of the factory to be erected at Neyveli.

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Domestic and Metallurgical Coke from South Arcot Lignite

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W. Germany

Influence of moisture, mineral matter, particle size distribution, pressure, rate of heating and temperature of carbonization on the physical and chemical properties of briquettes is discussed. Hydrogen bonds play a significant role in imparting strength to the briquettes. Good quality carbonized briquettes for domestic as well as metallurgical use can be produced from South Arcot lignite. Two-stage process is suggested for producing hard metallurgical double coke.

As lignite weathers rapidly, crumbles and finally disintegrates on exposure to air, it must be specially processed to facilitate storage, handling and transport over long distances. Lignite can be briquetted by pressure alone without the use of a binder. The role of moisture in briquetting of lignite has been discussed earlier[1,2]. Raw lignite briquettes can be used in industrial furnaces and specially designed domestic ovens, but are otherwise unsatisfactory giving rise to smoke and obnoxious tarry vapours in *chulas* (open domestic fires commonly used in India) in addition to considerable loss of unburnt carbon falling through the grate. Due to acute scarcity of charcoal and absence of any good quality coking coal in this region, it is essential to find out if South Arcot lignite can be processed to yield suitable fuel for domestic and metallurgical use.

LABORATORY EXPERIMENTS

Briquetting of Lignite. After air-drying for 2 to 3 days, the Neyveli lignite was passed through an impact mill with 2 mm. square sieve openings.

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*Present address: Neyveli Lignite Corporation Ltd, Neyveli, India.

TABLE 1—ANALYSIS OF NEYVELI LIGNITE

PROXIMATE ANALYSIS (as received)	%	ULTIMATE ANALYSIS (M.M.F.)	%
Moisture	53·6	Carbon	71·99
Ash	3·9	Hydrogen	4·98
Volatile matter	23·9	Sulphur	0·99
Fixed carbon	18·6	Nitrogen	0·72
Bulk density, kg./dm^3.	0·494	Oxygen	21·32

The crushed lignite was dried in a plate drier in an inert atmosphere to different moisture contents and briquetted in a Lousenhausenwerk electrically operated 60-ton hydraulic press. Typical analytical and operating data are given in Tables 1, 2 and 3.

Resistance to Weathering. Humidity of the atmosphere and moisture content of the briquettes influence the strength of raw briquettes on storage[3]. The resistance to weathering and disintegration on immersion in water of briquettes made from dried lignite containing 11·25-12·5 per cent moisture was greater than those made from other moisture contents. The influence of these factors on the compression strength of briquettes is given in Table 4.

Thermal Treatment of Briquettes. The raw briquettes were treated thermally in a suitable container in an inert atmosphere. The temperature was raised at 1°C./min. from 60° to 180°C. and then at 1·5°-2·0°C./min. to the final temperature. The influence of particle size and temperature of carbonization on the physical properties are given in Tables 5 and 6.

Strength of Briquettes. The mineral matter and the waxy matter of the raw lignite affect the strength of briquettes. Therefore two sets of experiments were done: Lignite was extracted with (*i*) hydrochloric acid, and (*ii*) with benzene-acetone mixture (80 : 20). The extracted material was washed free of acid or solvent and adjusted to 11·2 per cent moisture, briquetted and carbonized. Fig. 1 shows the briquettability characteristics of the extracted lignite samples. The results are given in Table 7.

PILOT PLANT TESTS

Briquetting of Lignite (Extrusion and Ring Roll Press). Moisture content and abrasion resistance of raw briquettes are the decisive influencing factors in the production of lumpy char[4]. It is essential that the briquetting material should be as fine and with as low a moisture content as possible. This is, however, greatly limited in commercial practice since dried fine coal requires higher briquetting pressures, and increases fire hazard and

TABLE 2—SIZE DISTRIBUTION OF CRUSHED LIGNITE

RAW CRUSHED LIGNITE		DRIED LIGNITE	
Size	%	Size	%
1—2 mm.	21·82	1—2 mm.	16·00
0·5—1 mm.	24·64	0·5 —1 mm.	20·00
<0·5 mm.	53·54	0·25—0·5 mm.	19·3
		0·06—0·25 mm.	34·7
		<0·06 mm.	10·0

TABLE 3—BRIQUETTING OF LIGNITE (HYDRAULIC PRESS)

(Lignite grain size, 0-2 mm.; Briquetting pressure, 6 × 700 kg./sq. cm.; Temp. of dried lignite and mould, 60°C.; Diam. of briquette, 60 mm.; Height of briquette, 40-41 mm.)

Moisture in dried lignite, %	17·6	15·4	12·5	11·25	9·6	8·4
Bulk density of dried lignite (kg./dm.^{3})	0·545	0·542	0·539	0·537	0·527	0·525
Density of raw briquette (kg./dm.^{3})	1·199	1·174	1·152	1·135	1·132	1·095
Compression strength (kg./sq. cm.)	224	210	195	190	180	180
Loss on abrasion (100 revolutions)-10 mm.	2·21	2·0	1·96	1·81	1·75	1·81

TABLE 4—INFLUENCE OF WEATHERING AND IMMERSION IN WATER ON THE COMPRESSION STRENGTH OF BRIQUETTES

(Briquetting pressure, 6 × 700 kg./sq. cm.)

MOISTURE IN BRIQUETTES %	COMPRESSION STRENGTH OF BRIQUETTES AFTER EXPOSURE TO ATMOSPHERE (in a covered shed) kg./sq. cm.					COMPRESSION STRENGTH OF BRIQUETTES AFTER IMMERSION IN WATER FOR 24 HR kg./sq. cm.	PERCENTAGE CHANGE IN COMPRESSION STRENGTH OF BRIQUETTES AFTER 24 HR IMMERSION IN WATER
	1st day	after 3 days	after 7 days	after 30 days	Percentage change in compression strength		
8·40	180	175	170	160	−11·10	95	−47·2
9·60	183	174	170	165	− 8·35	100	−45·3
11·25	190	185	190	190	—	136	−28·4
12·50	195	180	185	180	− 8·48	120	−38·4
15·40	210	195	180	150	−28·60	85	−59·5
17·60	224	180	150	120	−46·50	65	−71·4

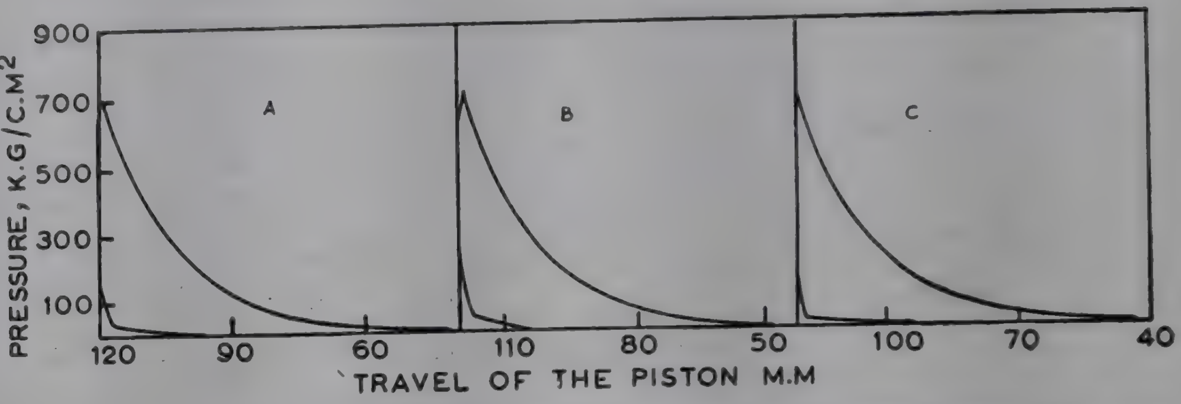

Fig. 1—Compression diagram for South Arcot lignite: (A) Untreated lignite (B) Lignite extracted with benzene-acetone mixture (C) Lignite extracted with hydrochloric acid

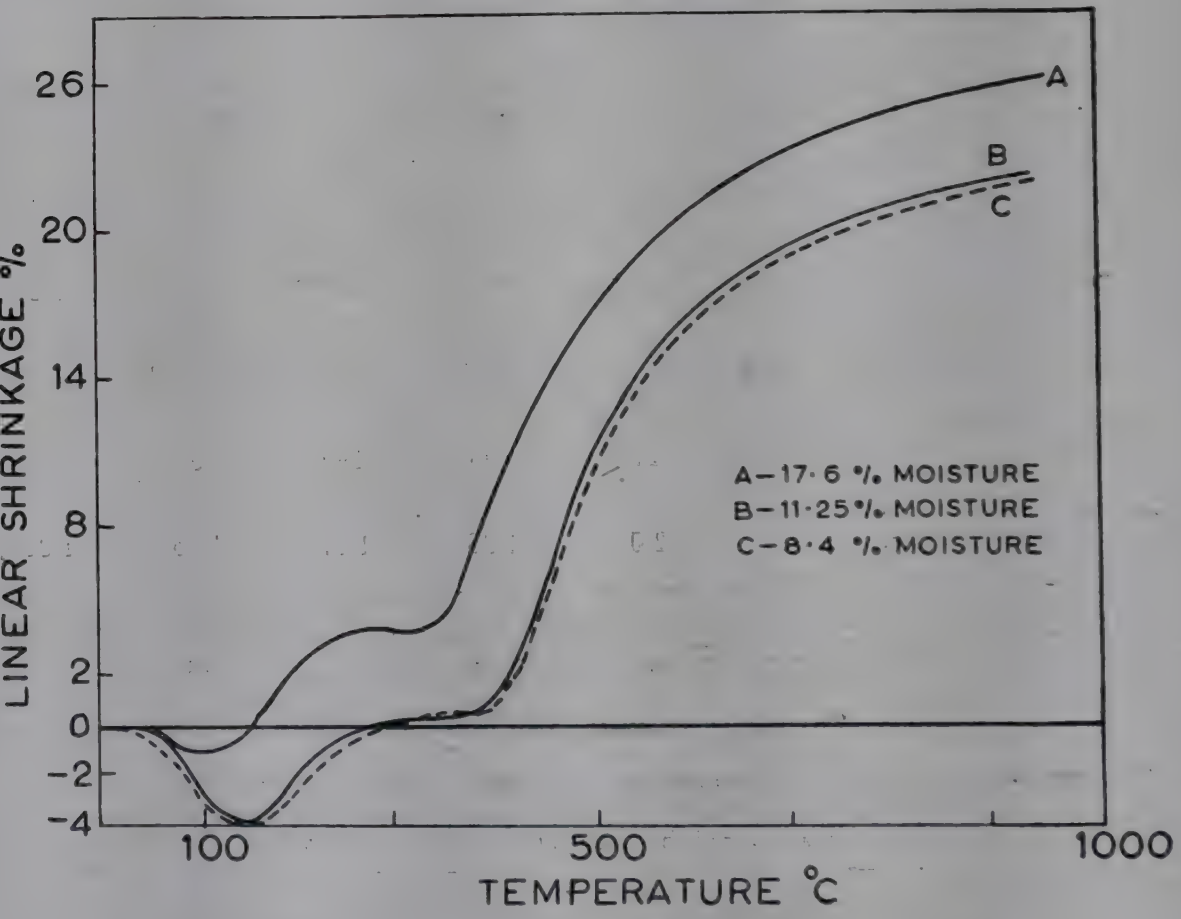

Fig. 2—Linear shrinkage of South Arcot lignite briquettes

loss of material. Dried, crushed lignite of 0-1 mm. (40 per cent below 60μ) size and 11·25 per cent moisture was briquetted in a 4 in. double lever extrusion press of 1 ton/hr capacity working at 60-70 r.p.m. The mould had a 5 mm. hump on each side. The oblong briquettes (97 mm. × 37 mm. × 22 mm.) were full of cracks and were not of uniform thickness. Briquettes from lignite of 0-2 mm. (10 per cent $<60\mu$) and 11·25 per cent moisture were strong with dark brown shining lustre.

Good quality shining briquettes with only few hair line fissures were obtained in a horizontal ring roll press of 100 kg./hr from lignite (0-1 mm.

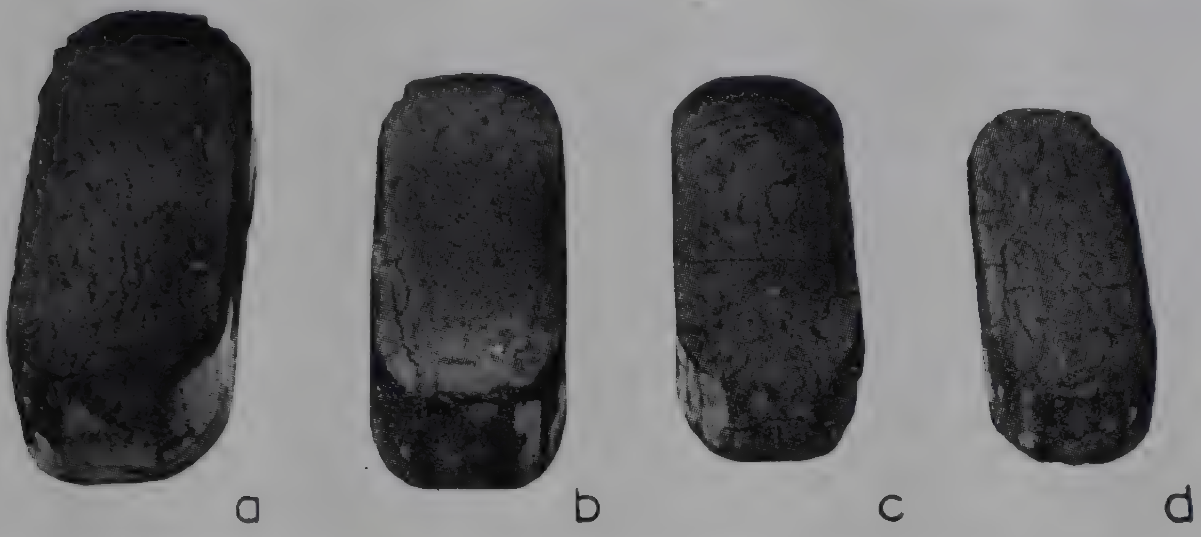

FIG. 3—EXTRUSION PRESS BRIQUETTES: (A) Raw briquettes (B) Carbonized to 470°C. (C) Carbonized to 580°C. (D) Carbonized to 950°C.

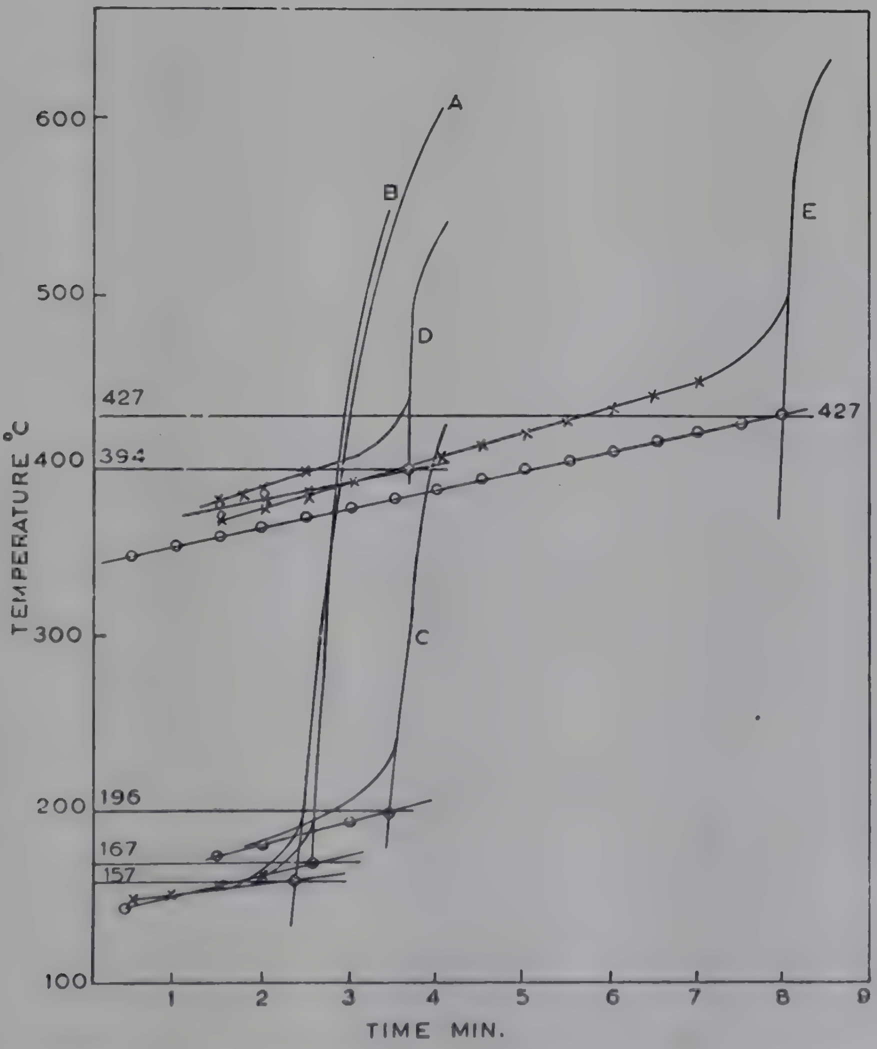

FIG. 4—IGNITION POINT OF COKE FROM SOUTH ARCOT LIGNITE: Carbonized at (A) 420°C. (B) 470°C. (C) 580°C. (D) 950°C. (E) Double coke

TABLE 5—PROPERTIES OF CARBONIZED BRIQUETTES (Hydraulic Press)

(Grain size of lignite used, 0-2 mm.; Briquetting pressure, 6 × 700 kg./sq. cm.)

	Temperature of carbonization, °C.		
	540	950	540
Moisture in raw briquettes, %	11·25	11·25	9·6
Compression strength of raw briquettes, kg./sq.cm.	190·0	190·0	183·0
Carbonized briquettes :			
Compression strength, kg./sq. cm.	240·0	290·0	200·0
Trommel test (100 revolutions)			
+10 mm.	94·7	97·8	74·2
+30 mm.	78·2	82·4	58·6
Volume shrinkage, %	40·7	51·4	40·0
Linear shrinkage, %	16·0	22·0	15·8
Density of briquette, kg./dm.^{3}	1·112	1·092	1·108
Porosity of briquettes, %	24·8	27·40	25·0
Ignition point, °C.	180·0	390·0	180·0

TABLE 6—EFFECT OF PARTICLE SIZE ON CARBONIZATION OF BRIQUETTES (Hydraulic Press)

Particle size, mm.	0-1	0-2
Moisture in dried lignite, %	11·20	11·25
Bulk density of dried lignite, kg./dm.^{3}	0·520	0·537
Briquetting pressure, kg./sq. cm.	6 × 1200	6 × 1200
Temp. of lignite and mould, °C.	60	60
Height of briquettes, mm.	30-40	40-41
Density of raw briquettes, kg./dm.^{3}	1·152	1·149
Compression strength, kg./sq. cm.	272	240
Temp. of carbonization, °C.	580	580
Compression strength, kg./sq. cm.	360	345
Trommel test (100 revolutions)		
+10 mm.	92·4	98·2
+30 mm.	68·4	84·2

TABLE 7—BRIQUETTING OF EXTRACTED LIGNITE

(Lignite particle size, 0-2 mm.; Briquetting pressure, 6 × 700 kg./sq. cm., Temp. of lignite and mould, 60°C.; Diam. of briquettes, 60 mm.; Weight of briquettes, 110 g.)

	UNTREATED LIGNITE	EXTRACTED WITH HYDROCHLORIC ACID	EXTRACTED WITH BENZENE-ACETONE MIXTURE
Moisture, %	11·20	11·30	11·20
Ash, %	7·38	5·40	8·46
Volatiles, %	46·00	45·94	36·42
Fixed carbon, %	35·42	37·36	43·92
Bulk density of lignite, kg./dm.^{3}	0·557	0·532	0·542
Height of briquettes, mm.	34·0	33·0	38·0
Density of briquettes, kg./dm.^{3}	1·135	1·140	1·124
Compression strength, kg./sq. cm.	190·0	204·0	135·0
Loss on abrasion (100 revolutions), −10 mm., %	1·50	1·40	48·30
Carbonized briquettes			
Compression strength, kg./sq. cm.	240·0	262·0	125·0
Loss on abrasion (100 revolutions), −10 mm., %	5·26	2·6	9·4

TABLE 8—LOW AND HIGH TEMPERATURE ASSAYS OF SOUTH ARCOT LIGNITE

TEMPERATURE OF ASSAY, °C.	520	900
(a) Yields of products (moisture-free basis), %		
Char	64·00	46·80
Tar	9·50	3·70
Light oil	0·60	1·50
Hydrogen sulphide	0·17	0·19
Water of decomposition	7·60	7·20
Gas + Loss	18·13	40·61
(b) Composition of gas, %		
CO_2	46·8	14·7
C_mH_n	2·1	6·2
CO	14·2	14·2
H_2	12·0	35·0
CH_4	22·5	24·2
N_2 (by difference)	2·4	5·7

TABLE 9—CARBONIZATION OF EXTRUSION PRESS BRIQUETTES

Temperature of treatment, °C.	460	580	1000
Yield, %			
Coke	57·20	51·00	39·00
Tar	9·40	10·20	10·20
Light oil	0·40	0·60	1·02
Water	11·20	11·20	11·20
Water of decomposition	5·30	6·70	6·60
Ammonia	0·01	0·06	0·10
Gas + Loss	16·49	20·24	31·88
Composition of gas, %			
CO_2	54·6	44·6	19·4
C_mH_n	2·3	1·7	5·4
CO	14·9	15·1	13·2
H_2	3·0	11·6	34·6
CH_4	21·5	24·4	22·9
N_2 (by difference)	3·7	2·6	4·5
Proximate analysis of char, %			
Moisture	1·14	1·20	1·20
Ash	10·20	14·90	16·70
Volatile matter	21·75	7·80	1·80
Fixed carbon	66·81	76·10	80·30
Residual tar	0·60	..	..
Physical properties of char			
Compression strength, kg./sq. cm.	276·0	280·0	290·0
Tumbler test (100 revolutions)			
+10 mm., %	90·4	92·8	92·6
+30 mm., %	63·8	64·2	68·4
Shatter test (6 drops from 1·6 meters)			
+20 mm., %	84·0	86·4	86·8
Density, kg./dm.^{3}	1·128	1·124	1·102
Porosity, %	20·6	24·40	27·30

TABLE 10—CARBONIZATION OF RING ROLL BRIQUETTES

TEMPERATURE OF TREATMENT, °C.	420	470	580	950
Yield, %				
Coke	64·80	56·80	51·80	39·50
Tar	7·20	10·05	10·80	11·56
Light oil	0·06	0·35	0·72	0·88
Hydrogen sulphide	0·16	0·18	0·23	0·32
Water	11·20	11·20	11·20	11·20
Water of decomposition	4·20	5·40	6·50	5·50
Ammonia	..	0·01	0·02	0·53
Gas + Loss	12·36	16·01	18·73	30·29
Composition of gas, %				
CO_2	58·2	52·8	40·6	13·5
C_mH_n	1·8	2·4	2·8	2·7
CO	12·6	12·6	16·4	20·4
H_2	9·8	4·8	12·0	37·0
CH_4	12·8	22·6	25·2	18·8
N_2 (by difference)	4·8	4·8	3·0	7·6
Proximate analysis of coke, %				
Moisture	1·14	1·20	1·30	1·0
Ash	9·92	10·70	14·75	16·6
Volatile matter	25·04	21·80	8·40	2·0
Fixed carbon	63·90	66·80	75·55	80·4
Residual tar (char basis)	1·20	0·60	..	..
Physical properties of char				
Tumbler test (100 revolutions), +10 mm., %	78·4	78·0	79·8	84·6
Shatter test (6 drops from 1·6 meter), +20 mm., %	78·8	78·6	80·4	82·0
Density, kg./$dm.^3$	1·131	1·130	1·128	1·110
Porosity, %	18·9	20·0	24·0	26·4

TABLE 11—PROPERTIES OF LOW TEMPERATURE TAR FROM SOUTH ARCOT LIGNITE

Temp. of carbonization		580°C.
Sp. gr. at 50°C.		0·960
Distillation of tar (W.F.)		
Temp. at which distillation begins		97°C.
Fraction		*Yield, %*
<180°C.		8·20
180°—230°C.		14·80
230°—270°C.		21·20
270°—300°C.		7·20
300°—320°C.		6·30
320°—360°C.		17·80
Pitch		22·40
Loss		2·10
Viscosity of tar at (*a*) 50°C.	1·94°E.	
(*b*) 60°C.	1·56°E.	
(*c*) 70°C.	1·38°E.	
(*d*) 80°C.	1·29°E.	
Softening point of pitch, °C.		42·00
Ash in tar, %		0·414
Benzol-insoluble, %		0·254
Tar acids, %		20·67
Pyridine bases, %		0·91
Paraffin content, %		12·40
Phenol in liquor, %		0·76

and 0-2 mm.) with 11·25 per cent moisture at 1500 kg./sq. cm. pressure. The size of the briquettes was 37 mm. × 30 mm. × 16 mm.

Thermal Treatment of Briquettes. The results of high and low temperature assays of air-dried lignite done according to Bauer and Fischer are given in Table 8. The briquettes were thermally treated at 420°, 470°, 580° and 950°C. in Jenkner retort. The temperature was raised at 1°/min. up to 180°C., at 1·5°/min. from 180° to 450°C. and at 3°/min. from 450° to 950°C. The yields of products and the physical properties of the briquettes

TABLE 12—DOUBLE COKE FROM SOUTH ARCOT LIGNITE

SL NO.	LIGNITE CHAR	BINDER, %			TEMPERATURE OF PRIMARY CARBONIZATION, °C.	TEMPERATURE OF SECONDARY CARBONIZATION, °C.	TIME OF SECONDARY CARBONIZATION, hr	BREAKING STRENGTH OF RAW BRIQUETTES, *kg.*	DOUBLE COKE		REMARKS
		Coking coal	Tar	Pitch					Abrasion index, +10 *mm.*	Breaking strength, *kg.*	
1.	85 (0-0·5 mm.)	..	10	5	380	..	..	..	..	..	Mixture could not be briquetted
2.	80 (0-0·5 mm.)	..	12	8	380	..	..	20	..	..	Raw briquettes of poor strength
3.	50 (0-0·3 mm.)	30 (0-0·3 mm.)	12	8 (Fluid)	380	1000	3	Soft 50	81	120	Lump molten coke
4.	The same mixture as in No. 3				380	600	3	do	79	120	do.
5.	50 (0-0·5 mm.)	30 (0-0·3 mm.)	10	10	380	1000	3·5	18-20	87·5	125	Molten coke, edges deformed and partly fused
6.	55 (0-0·5 mm.)	25 (0-0·5 mm.)	8	12	450	1000	3·5	15-18	89·4	135	Very little fused
7.	64 (0-0·6 mm.)	20 (0-0·6 mm.)	6	10	450	600	3·5	18	84·5	130	Very little fused, strong coke
8.	65 (0-0·6 mm.)	20 (0-0·6 mm.)	9	6	600	1000	3·0	22	84·1	127	Slightly fused good coke briquettes
9.	70 (0-0·6 mm.)	15 (0-0·3 mm.)	5	10	600	1000	3·0	30	92·0	138	do

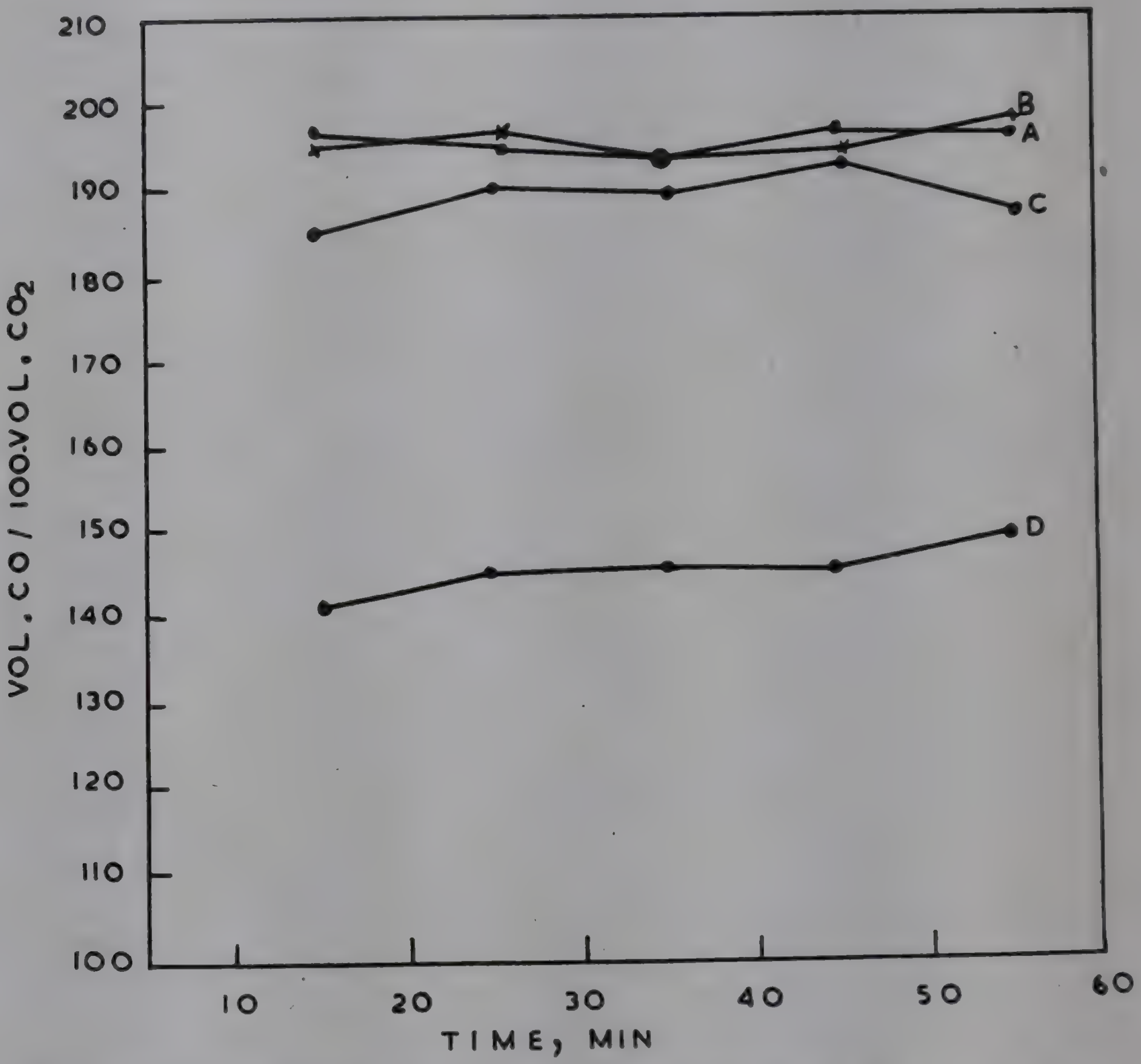

FIG. 5—REACTIVITY OF CHAR TO CARBON DIOXIDE: Carbonized at (A) 470°C. (B) 540°C. (C) 950°C. (D) Form coke

and tar are given in Tables 9-11. Briquettes treated up to 420°C. and 470°C. were further treated in a Fischer assay retort to determine the residual tar. Fig. 2 shows the linear shrinkage of briquettes on thermal treatment. Fg. 3 shows extrusion press carbonized briquettes. Ignition point of char samiples was determined according to K. Bunte and Windorfer and is shown in Fig. 4. The briquettes burn with a long blue flame and do not give any smoke or tarry smell.

Double Coke from South Arcot Lignite. The high briquetting pressure, the high reactivity (Fig. 5) of the char to carbon dioxide, the low yield of char (18-20 per cent on raw lignite basis) the slow heating rate essential for getting strong carbonized briquettes, size of the briquettes, and the disposal of char fines from single stage carbonization make it necessary to find alternative processes to overcome these difficulties. Lignite is not endowed with the property to agglomerate on heating. Addition of binders and/or coking coal to the dried lignite does not yield coherent mass on carbonization; briquetting of dried lignite with these binders at low pressure (up to 200 kg./sq. cm.) and subsequent carbonization does not result in a strong product because of the difference in the nature and rates of devolatilization of the constituents. Lignite, besides being hydrophilic, gives out copious quantities of volatiles at lower temperatures and therefore primary heat treatment or degasification is essential before it can be mixed with binders and briquetted. The high specific surface of char necessitates large quantities of tar and pitch as binder. The addition of coking coal greatly reduces the binder requirement. The advantage of the two-stage process is that all the tar is recovered as high temperature tar but the thermal efficiency is low as the char from primary carbonization is cooled before briquetting. It may be worthwhile to combine the above two processes and use only the resultant char fines from first stage carbonization for double coke manufacture.

EXPERIMENTAL

Air-dried lignite (8-10 mm.) was degasified in a metallic retort, reduced to required size, mixed thoroughly with the binder and briquetted in a double roll press. The cushion-shaped raw briquettes were carbonized in a muffle furnace. Table 12 gives the point breaking strength and trommel abrasion index of the resultant product.

DISCUSSION

Moisture. Table 4 shows that briquettes made from lignite having more than 15 per cent moisture content were neither weather resistant, nor resistant to disintegration under water, while briquettes made from lignite having 11 to 12 per cent and especially those made at higher pressures retained their shape on immersion in water, even after 15 days. The poor qualities of high-moisture lignite briquettes have already been discussed[2]. The bonds imparting strength to low-moisture lignite briquettes are tightly held, i.e. one water molecule is held by two cooperating polar groups in addition to the forces of cohesion, emanating from the plastic flow[5,6] of coal molecules under high pressures. Behaviour of briquettes with different moisture contents, on thermal treatment, given in Fig. 2, further confirms the hypothesis advanced. Expansion in earlier stages of heating in case of high moisture briquettes is considerably less than in case of those with lower moisture. In the former case the particles are held together by weaker bonds, which break easily as the temperature rises, while in the latter case, the strong cohesive forces prevent the escape of volatiles resulting in the shrinkage commencing only at much higher temperatures at which the active degasification of lignite begins.

Mineral Matter. The elastic recovery and, therefore, the briquettability index varies with the changes in mineral matter content[7,8]. Fig. 1

shows the behaviour of South Arcot lignite treated with hydrochloric acid and extracted with benzene-acetone mixtures under compression. Table 7 shows that the strength of green and carbonized briquettes made from hydrochloric acid extracted lignite is greater than of those from untreated lignite because the differential thermal stresses are much less in the former because of the presence of more uniform ground mass and less mineral matter.

Particle Size. In lignite briquetting the grain size and the shape of particles play an important role in imparting strength; the greater the surface area of particles in contact, the greater is the strength of briquettes. It was, however, difficult to briquette lignite of size 0-1 mm. (40 per cent below 60 μ) with 11·25 or lower moisture content in the extrusion press, probably due to presence of excessive fines, insufficient pressure and high hump in the mould. The briquettes were full of cracks, had varying thickness, and resulted in poor carbonized briquettes. Briquettes from 0-2 mm. size lignite with the same moisture content gave better results. The findings are in conformity with those of Rammler[9].

Ring roll briquettes with 11·25 per cent moisture are more sensitive to thermal treatment than those made from extrusion press.

Rate of Heating. The rate of heating has considerable effect on the strength of carbonized briquettes[10]. On heating, as lignite does not pass through the plastic state, the carbonized lignite briquettes are sustained by shrinkage strength caused by slow and uniform rate of heating. The briquettes should be heated very slowly as the formation of cracks is governed by the balance between disruptive forces due to loss of volatiles on heating and forces of cohesion. This is further augmented by the differential thermal stresses between the surface and core of the briquette at higher rates of heating.

Escape of water vapour and volatiles in the initial stages of carbonization should therefore be as slow and uniform as possible. There is substantial loss of volatiles and great volume change up to 600°C. Above this temperature there is very little change of volatiles or shrinkage (Fig. 2). The rate of heating above 600°C. can be considerably increased, without affecting the physical strength of the carbonized briquettes. The influence of rate of heating in the initial stages is shown in Fig. 6.

Temperature of Carbonization. The quality and the quantity of different products depend upon the final temperature of carbonization. The strength of carbonized briquettes increases with the increase in the final temperature of carbonization. For the maximum yield and ease of ignition of domestic coke, the temperature of carbonization should be low, but it should not contain any tar, which gives smoke. Besides, at low temperatures the quantity and quality of gas (high density and CO_2 content) are inadequate for under-firing. The optimum carbonization temperature for domestic coke production is about 500°C.

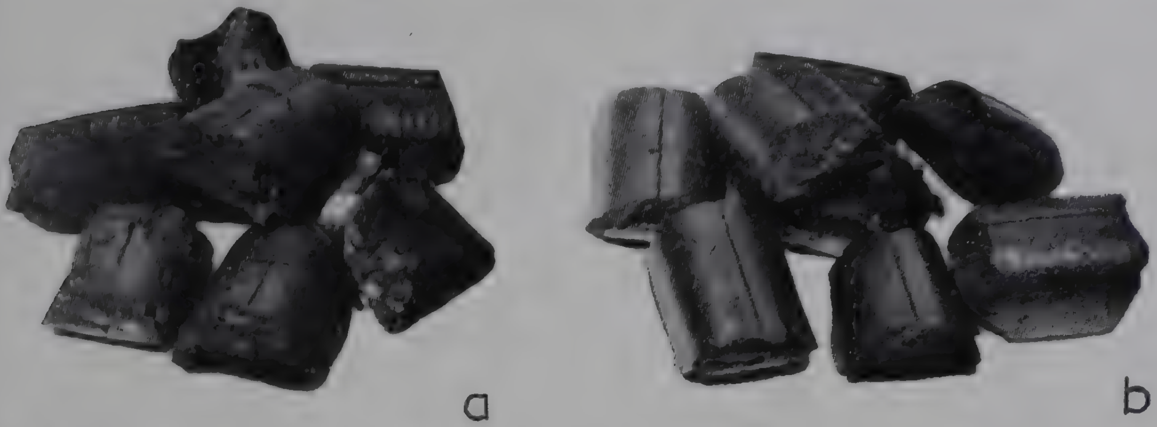

FIG. 6 – BRIQUETTES FROM RING ROLL PRESS: Rate of heating (a) 2·5°C./min. (b) 1°C./min.

Metallurgical Coke. Metallurgical fuel should have low volatile content (not exceeding 2 per cent), and this can be achieved by carbonizing the briquettes at 950°C. The carbonized char has quite different physical properties from those of normal coke. The briquettes are marked by high density and low macroporosity. The fine pore structure of char makes it highly reactive and hygroscopic. The high reactivity results in great solution loss in cupola and blast furnace operations, but is partly compensated for by high density and low porosity (25-27 per cent as compared to 40-50 per cent for normal coke). Single-stage carbonization limits the size of coke produced and also results in considerable quantities of char fines. These char fines can be successfully utilized in double coke production and the same can be used satisfactorily for metallurgical purposes[11].

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DISCUSSION

Shri S. Sarkar: What is the briquettability of lignite with zero moisture content ?

Shri D. N. Sibal: There exists a relationship between the moisture content and the briquetting pressure. With decrease in moisture in the dried lignite there is a corresponding increase in the pressure required for briquetting. It is possible to briquette lignite with zero moisture content but the pressure required is rather very high. In commercial practice, it may not be justifiable because of the excessive wear and tear of the die. In addition, dry lignite powder is very reactive and may present fire and explosion hazards.

Dr A. B. Chatterjee: I am interested in the performance of lignite briquettes in the low shaft furnace. The rate of throughput in the furnace depends on the combustion of briquettes and hence on their reactivity. The authors stated that increase in reactivity results in great solution loss. The solution loss depends upon equilibrium between oxides of iron. Why is high reactivity considered undesirable ?

Shri D. N. Sibal: Low reactivity is desirable because the reduction of iron ore takes place mostly in the combustion zone. It may not be possible to attain very high temperatures because of the high reactivity and fast burning out of the fuel. In addition, the gaseous reduction in the shaft is very little because of the short time of contact and low height of the shaft. This results in a high percentage of carbon monoxide in the exhaust gases.

Dr V. A. Altekar: Conditions in the blast furnace are different from those in the low shaft furnace. Reduction occurs in the former case in the gaseous state, whereas in the latter, it takes place in the solid state.

Dr SM. Lakshmanan: The authors have stated that hydrochloric acid removes the mineral matter. Treatment with hydrochloric acid removes calcium. Is it the removal of calcium or the increase in humic acid that is responsible for improving the briquettability ?

Shri D. N. Sibal: It cannot be said with certainty whether it is the removal of calcium or increase in the humic acid content that is responsible for increase in strength of the briquette. It certainly is due to the decrease in the mineral content of coal. Please refer to the paper on "Further studies on briquetting properties of Indian lignite" presented by Dr M. S. Iyengar, where the authors use calcium treatment for improving the briquette strength.

Dr L. R. Vaidyanath: What is the electrical resistance of lignite ? This property as well as phosphorous content of lignite are important in electrical smelting of iron.

Shri D. N. Sibal: No studies were undertaken to determine electrical resistance. The phosphorous content is very low. Lignite ash contains phosphates ranging from traces to 0·10 per cent.

Further Studies on Briquetting Properties of Indian Lignite

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Kashmir lignite pretreated with lime water was successfully briquetted at low pressures of 1-2 tons/sq. in. without addition of a binder. High-pressure briquetting of Kutch lignite is also described. South Arcot lignite preheated to 200°-300°C. yielded completely water-resistant briquettes. Humic-acid-free lignite has better briquetting properties than lignite or humic acid.

Lignite occurs in various parts of India and the problem of its utilization has assumed importance in recent years. Several papers[1-9] have dealt with the properties of Indian lignites and their utilization. The present paper deals with the briquetting properties of Kashmir, Kutch and South Arcot lignites and of humic acids obtained from lignites.

KASHMIR LIGNITE

Lignite occurs in the Kashmir Valley in the Shaligange River, Firozpur Nala sector and the reserves are estimated to be over 84 million tons. Lignite is at present mined to a limited extent in the Nichahom area and the main sources of domestic and industrial fuel still continue to be wood and charcoal. A Kashmiri spends on an average as much as 30-50 per cent of his income on fuel, and hence the importance of a cheap and more efficient fuel with lignite as the base.

Kashmir lignite, however, is of an inferior variety. It contains as much as 40 per cent mineral matter. The average analysis is given in Table 1. Like any other lignite, it can be briquetted at high pressure without a binder[3], but the briquettes thus obtained are difficult to burn. The ash

TABLE 1—ANALYSES OF LIGNITES

LOCALITY	AIR-DRIED BASIS					DRY MINERAL MATTER-FREE BASIS							
	Moisture %	Ash %	V.M. %	F.C. %	C.V. (Btu/lb.)	V.M. %	F.C. %	C %	H %	S %	N %	O %	C.V. (Btu/lb.)
Umarsar (Kutch)	18·20*	15·40	35·50	30·90	8,740	53·80	46·20	68·87	5·25	1·81	0·93	23·14	13,070
South Arcot	23·00	5·80	39·80	31·40	8,312	55·54	44·46	71·99	4·98	0·99	0·72	21·32	11,770
Kashmir	17·60	39·70	27·40	15·30	4,535	60·50	39·50	67·89	5·29	0·96	1·96	23·90	11,710

*At 60% relative humidity and 40°C.

TABLE 2—BRIQUETTING OF KASHMIR LIGNITE

NATURE OF TEST	WITH LIME WATER				WITH 1% SOLN OF SODIUM HYDROXIDE		WITH WATER		WITH 10% PITCH	WITH 10% PETROLEUM BITUMEN
	Briquettes before drying	Sun-dried briquettes	Room-dried briquettes	Mixture kept overnight, briquetted and room-dried	Sun-dried briquettes	Mixture kept overnight, briquetted and sun-dried	Briquettes before drying	Briquettes after drying		
Shatter index (5 lb., 4 drops) Cum. %, +½ in.	52·5	55·0	85·0	60·0	65·0	75·0	56·25	28·75	62·5	85·0
American abrasion index %, −3/16 in.	55·0	12·5	15·0	45·0	52·5	25·0	55·0	87·5	50·0	12·5

produced during burning forms an impermeable coating which hampers further combustion. The mineral matter is intimately mixed with the lignite and is not amenable to washing by any of the conventional methods. X-ray studies[10] have indicated that the mineral matter mainly comprises clay minerals of the illite type finely dispersed in colloidal dimensions. Alkali extraction showed that nearly 90 per cent of the coaly portion in lignite is present as humic acid and the method was tried for separation of the coaly portion from the mineral matter. During these experiments it was noticed that the alkali-extracted material sets to a hard solid substance difficult to break, suggesting the possibility of briquetting Kashmir lignite at low pressure. Pre-treatment of lignite with 1 per cent alkali solution or with lime water enabled it to be briquetted at low pressures. Lime water was mixed with Kashmir lignite (about 30 per cent) in a mechanical mixer to give the right consistency. The mix was then briquetted in an ovoid roller briquetting plant of 1·5 ton/hr capacity, and the briquettes tested. For the Shatter index, 5 lb. of the briquettes were dropped from a height of 6 ft on a metallic plate of 4 ft diam. and the product screened through 1 in. and 0·5 in. square sieves. The Abrasion index, which is a tentative American Standard[11], was obtained by tumbling 5 lb. of briquettes for 120 revolutions at 30 r.p.m. in a hexagonal drum carrying 3/16 in. slits along the entire length. The index is expressed as the percentage passing through the slits in the drum. Table 2 presents details of the results obtained. For comparison the strength of the briquettes obtained with pitch and petroleum bitumen binders are also shown. It will be seen that the strength of briquettes obtained by lime treatment are superior in strength to those obtained with pitch and comparable to those obtained with petroleum bitumens.

The important point that emerges is that it is possible to briquette Kashmir lignite at low pressures. This is the first example known showing the possibility of lignite being briquetted at low pressures. The exact role of lime water in improving the briquetting properties of the lignite is not fully understood. A plausible explanation is that the colloidal clay particles are surrounded by similarly charged double layers which prevent them from coming near to each other due to repulsion forces. On lime treatment the electric charges are disturbed and the clay particles are able to come near each other to form a continuity which acts as the binder for the lignite particles.

The Kashmir lignite briquettes obtained at low pressures burn excellently and since they do not produce much smoke could be used as domestic fuel. The Central Fuel Research Institute is installing a 10 tons/hr briquetting plant at Srinagar for briquetting lignite using the above technique.

KUTCH LIGNITE

Lignite occurs in the Umarsar, Lefri, Jhulrai and Barunda areas of

TABLE 3—DISTRIBUTION OF SULPHUR IN KUTCH LIGNITE

	Air-dried at 18·20% moisture	Dry	% of total sulphur
Sulphate sulphur	0·28	0·34	9·03
Pyritic sulphur	1·61	1·97	51·94
Organic sulphur	1·21	1·48	39·03
Total	3·10	3·79	100·00

TABLE 4—REACTIVE GROUPS IN LIGNITE

Dry mineral matter-free	Umarsar (Kutch)	South Arcot
Hydroxyl group (-OH)	10·00	9·28
Carbonyl group (-CO)	1·36	4·05
Carboxyl group (-COOH)	5·29	2·20
Total oxygen	23·14	21·32

Kutch. The Umarsar area has an estimated reserve of 14·36 million tons and an inferred reserve of 3·19 million tons. The Lefri area has an additional reserve of 1·53 million tons of lignite. Since this lignite occurs in Western India which does not have an alternative reserve of solid fuel, the processing of this lignite is of importance. This lignite can be briquetted only at high pressures and not at low pressures like Kashmir lignite.

Lignite samples were received from Umarsar, covered with water in sealed drums to avoid oxidation, loss of moisture and capillary shrinkage. These were sampled according to standard specifications and then crushed to —6 mesh and —72 mesh B.S.S. in stages. Proximate and ultimate analyses of this lignite are included in Table 1, the distribution of sulphur in Table 3 and reactive functional groups in Table 4, which also contains, for comparison, the analysis of South Arcot lignite.

Portions of the base samples were dried to different moisture contents in an electrically heated oven and briquetted in a 50-ton hydraulic press using a plunger type mould. The experimental procedure adopted was similar to that described earlier[1,2]. The briquettes made were of cylindrical shape, 1·33 in. in diam. and 1·2 in. in height. The briquettes were subjected to compression strength tests in an electrically operated hydraulic machine, and the pressure at which the briquettes collapsed was taken as indicative of its strength. The results obtained are shown in Figs. 1-3.

The briquettes were also carbonized to 900°C. at 2°C./min. in an electrically heated furnace capable of holding four briquettes at a time, the rate

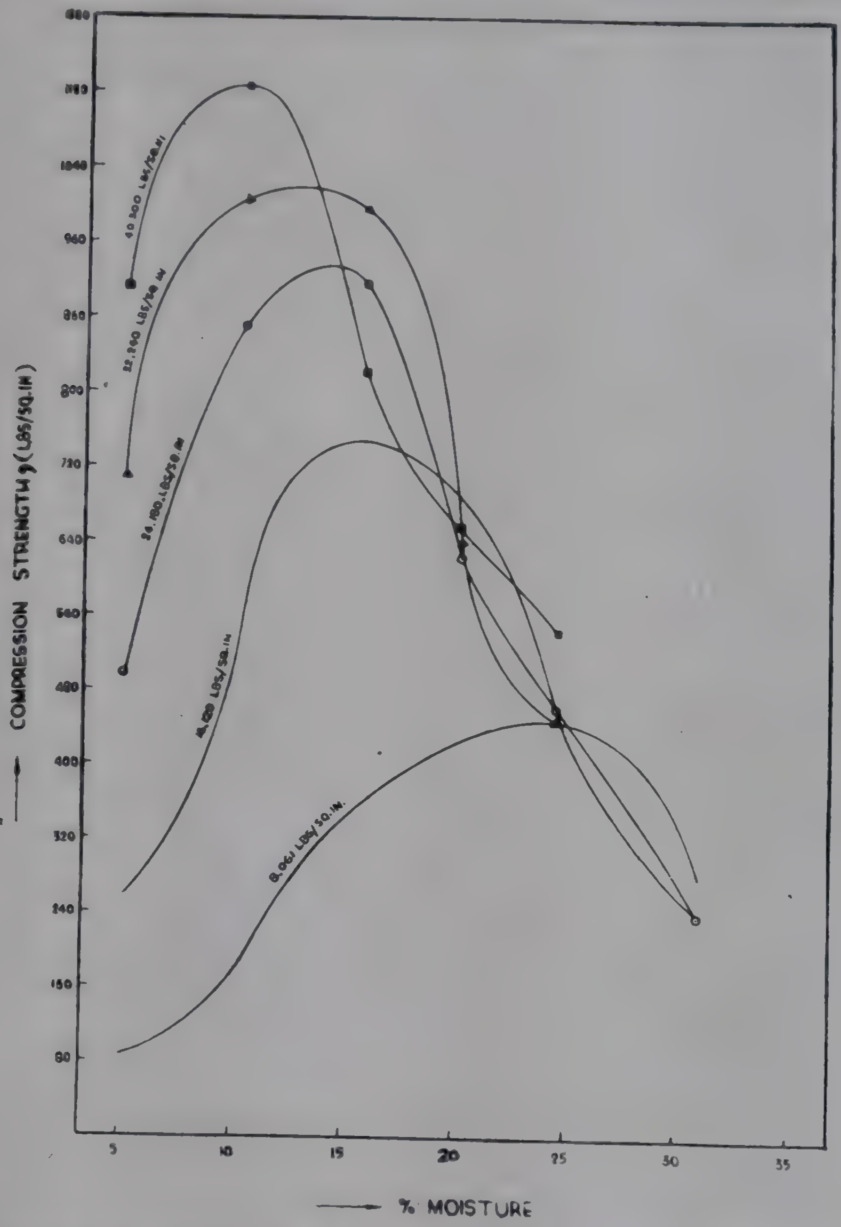

FIG. 1—INFLUENCE OF PRESSURE AND MOISTURE ON THE BRIQUETTING OF KUTCH (UMARSAR) LIGNITE (—6 mesh)

of heating being deemed best from previous experiments[3,5]. The briquettes were allowed to cool and again tested for their compression strength (Fig. 3).

Earlier studies on lignite had indicated that the critical moisture content (needed for optimum strength) was almost independent of briquetting pressures. For Kutch lignite, however, the critical moisture content varies with briquetting pressure, decreasing with increase in briquetting pressure (Fig. 1). The strength of the briquettes obtained with —72 mesh B.S.S. lignite (Fig. 2) are higher than those obtained with —6 mesh, though, in both cases, the strength of the briquettes increased with increase in the briquetting pressure. The briquetting properties of Kutch lignite are, however, inferior to those of other Indian lignites studied[1-2].

One would have expected[8] the briquetting properties of Kutch lignite to be superior to those of South Arcot and other Indian lignites, as the

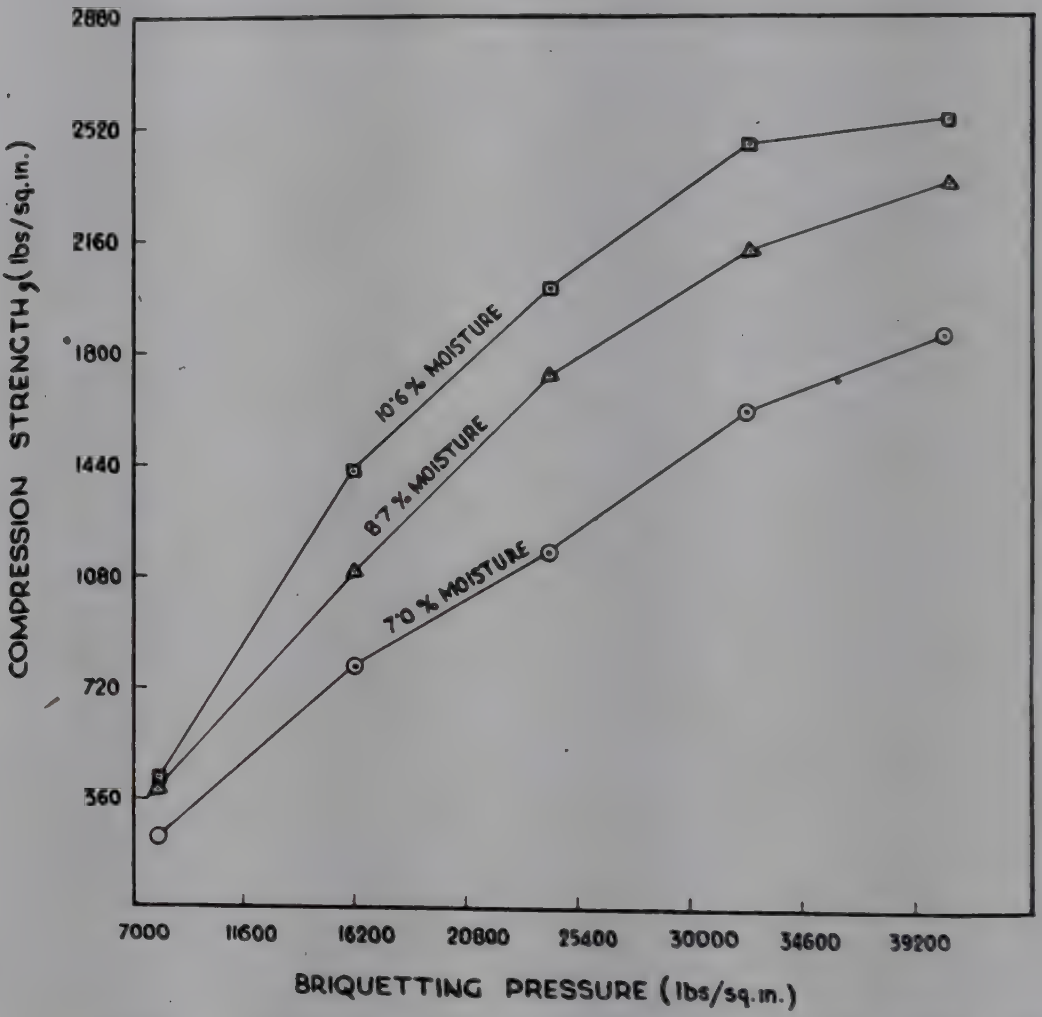

FIG. 2—INFLUENCE OF PRESSURE AND MOISTURE ON THE BRIQUETTING OF KUTCH (UMARSAR) LIGNITE (—72 mesh)

Kutch material is younger in rank than South Arcot, Palana or Kashmir lignites (Table 1). The functional groups which determine the briquette strength are also greater than in South Arcot lignite (Table 4). But actually this is not so.

The strength of the Kutch lignite briquettes increased considerably on carbonization (Fig. 3) and also, in general, with initial briquetting pressures and initial moisture content (up to 10·6 per cent) of the green briquettes. The strength obtained was, however, lower than for corresponding South Arcot lignite briquettes.

The briquetting properties of Kutch lignite, though inferior to those of South Arcot and Palana, Kutch lignite gives fairly strong briquettes, the optimum moisture content varying with briquetting pressures. Carbonized briquettes are superior in strength to green briquettes.

SOUTH ARCOT LIGNITE

South Arcot lignite can be briquetted merely by application of high pressures without addition of binder, but the briquettes thus obtained are not water-resistant.

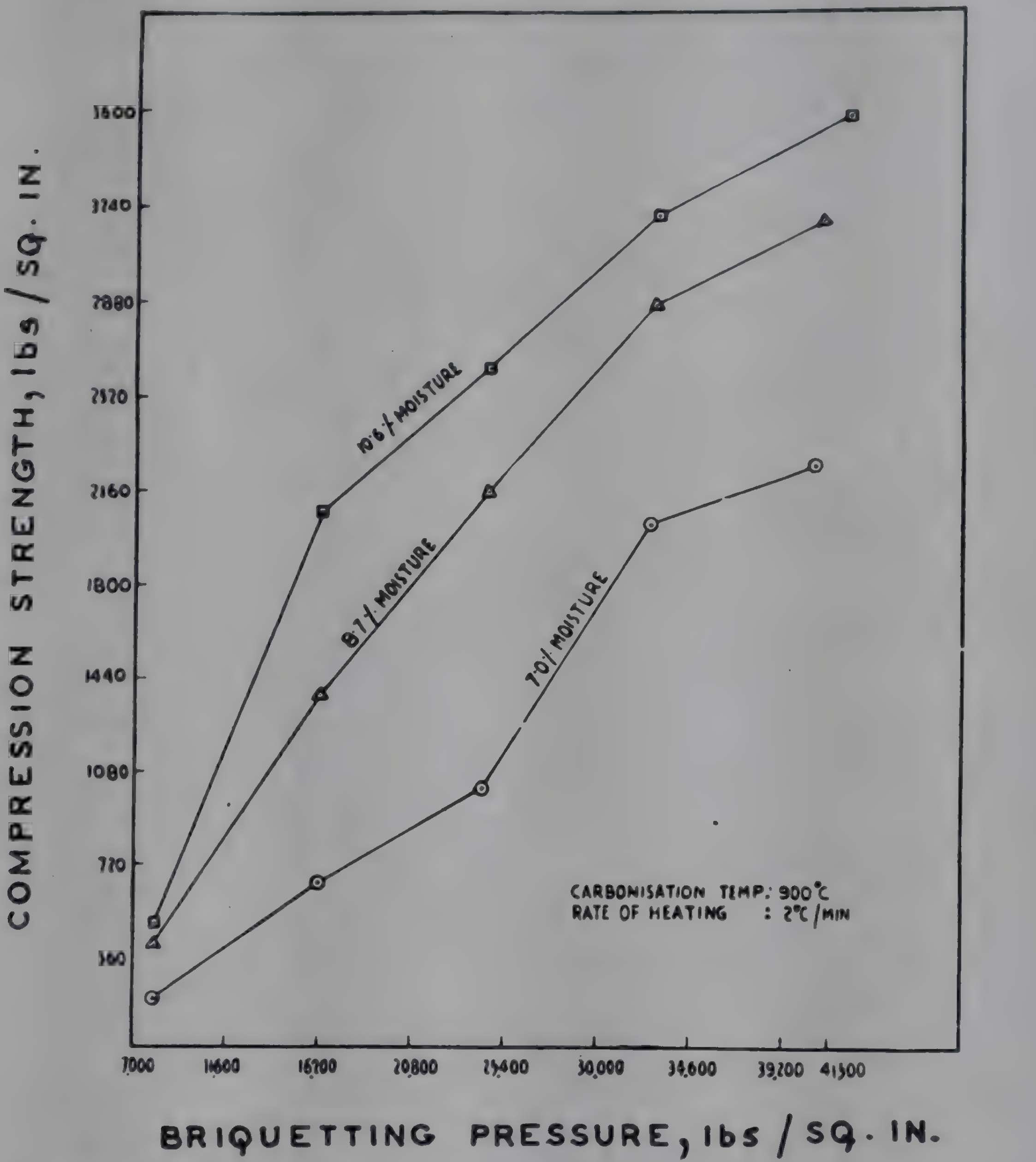

FIG. 3—INFLUENCE OF BRIQUETTING PRESSURE ON THE STRENGTH OF CARBONIZED KUTCH (UMARSAR) LIGNITE BRIQUETTES (—72 mesh)

A process[12] has been developed whereby lignite briquettes can be made completely water-resistant.

Lignite is heated in a finely powdered form to temperatures varying between 100° and 400°C. in the absence of air either in a static or fluidized bed for 2-3 hr depending on the nature of lignite and the strength of the briquettes desired. The sample is then cooled in the absence of air and the moisture is adjusted by adding the requisite amount of water (5-16 per cent) and mixing it thoroughly.

The mix is then briquetted in a hydraulic or extrusion press. The results obtained are presented in Figs. 4-8. It is clear from the strength of the briquette before and after immersion in water for 24 hr that untreated lignite does not give a water-resistant briquette (Fig. 4).

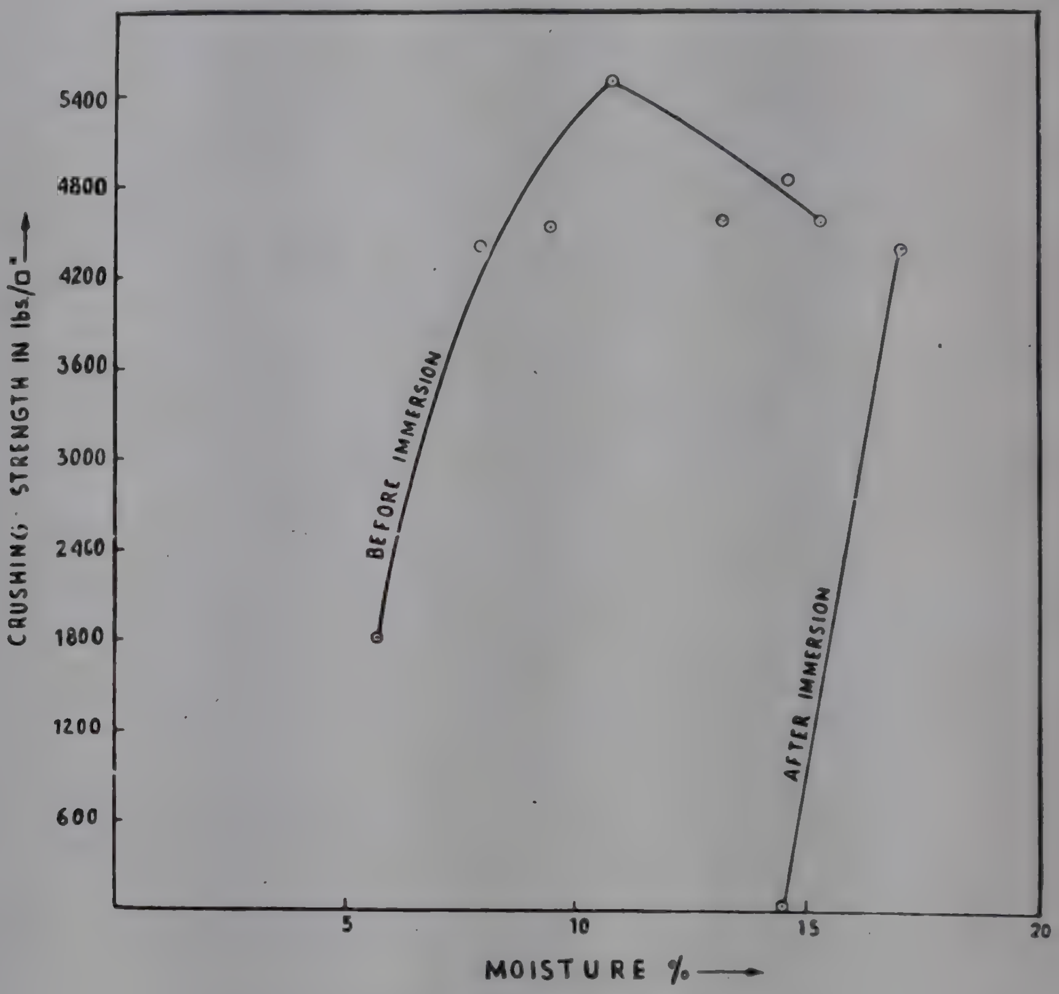

FIG. 4—SOUTH ARCOT LIGNITE NOT PREHEATED

The critical moisture required to obtain maximum strength after water immersion, decreases with increase in the temperature of pre-treatment. Best results are obtained by heating South Arcot lignite at 200°C. and briquetting it at 17-18 per cent moisture.

BRIQUETTING PROPERTIES OF LIGNITE

To understand the mechanism which makes the briquettes water-resistant, the briquetting properties were studied of humic acid obtained from South Arcot lignite, of humic acid-free South Arcot lignite and of bitumen obtained from South Arcot lignite. The humic acids were separated from lignite by extraction with strong sodium hydroxide solution and subsequent addition of hydrochloric acid. The dried humic acid was briquetted in a hydraulic press and the crushing strength of the briquettes determined in a universal compression testing machine. For comparison, South Arcot lignite, humic acid-free lignite and bitumen-free lignite were briquetted under similar conditions. The bitumen-free lignite was obtained by extracting the lignite with benzene and alcohol mixture (1 : 1) in a Soxhlet apparatus. The results obtained are presented in Table 5. While the

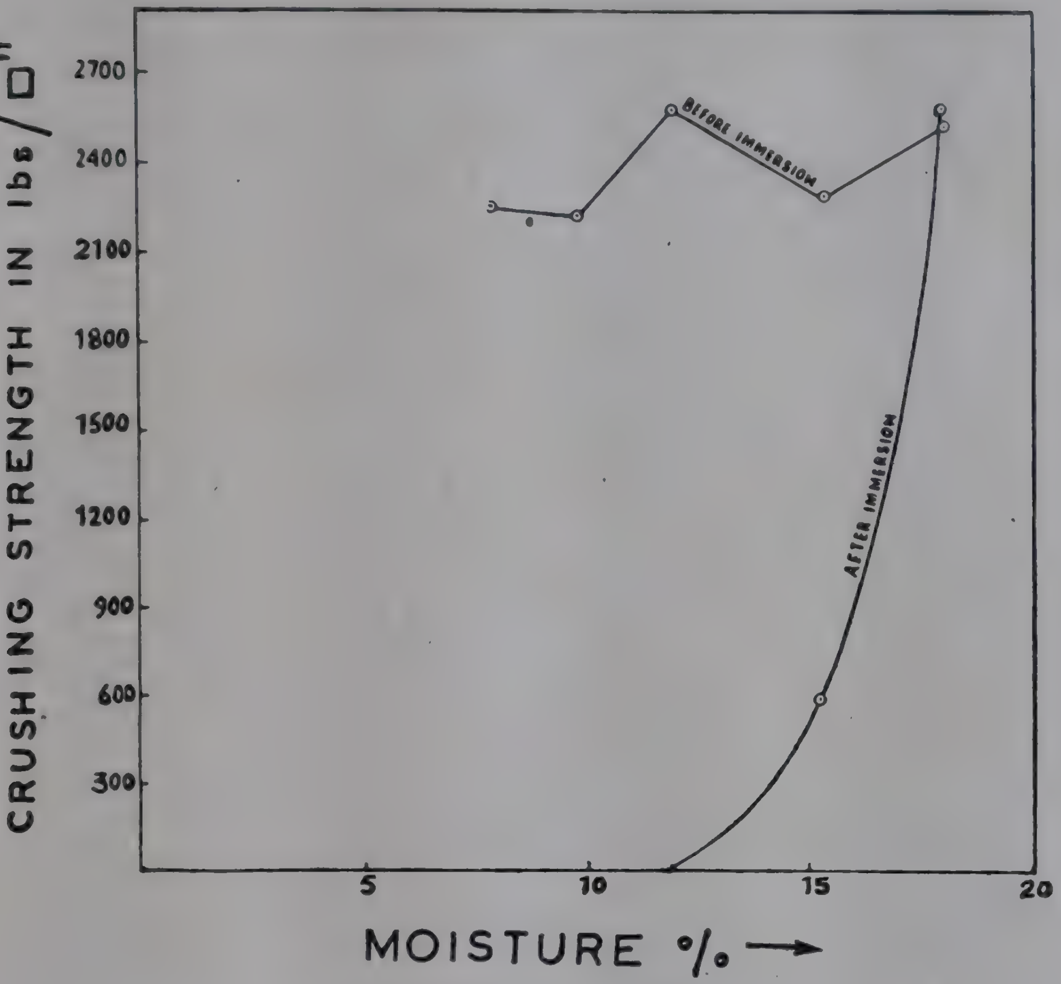

Fig. 5—South Arcot lignite preheated to 200°C.

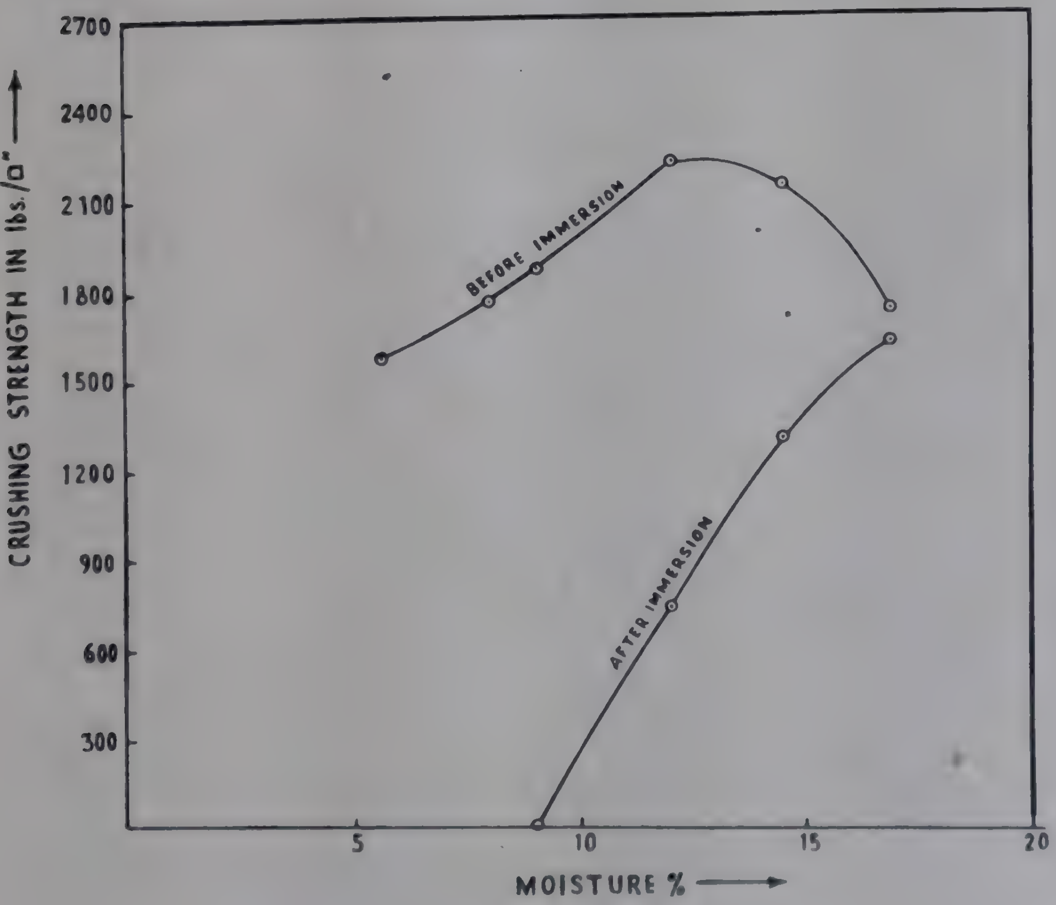

Fig. 6—South Arcot lignite preheated to 250°C.

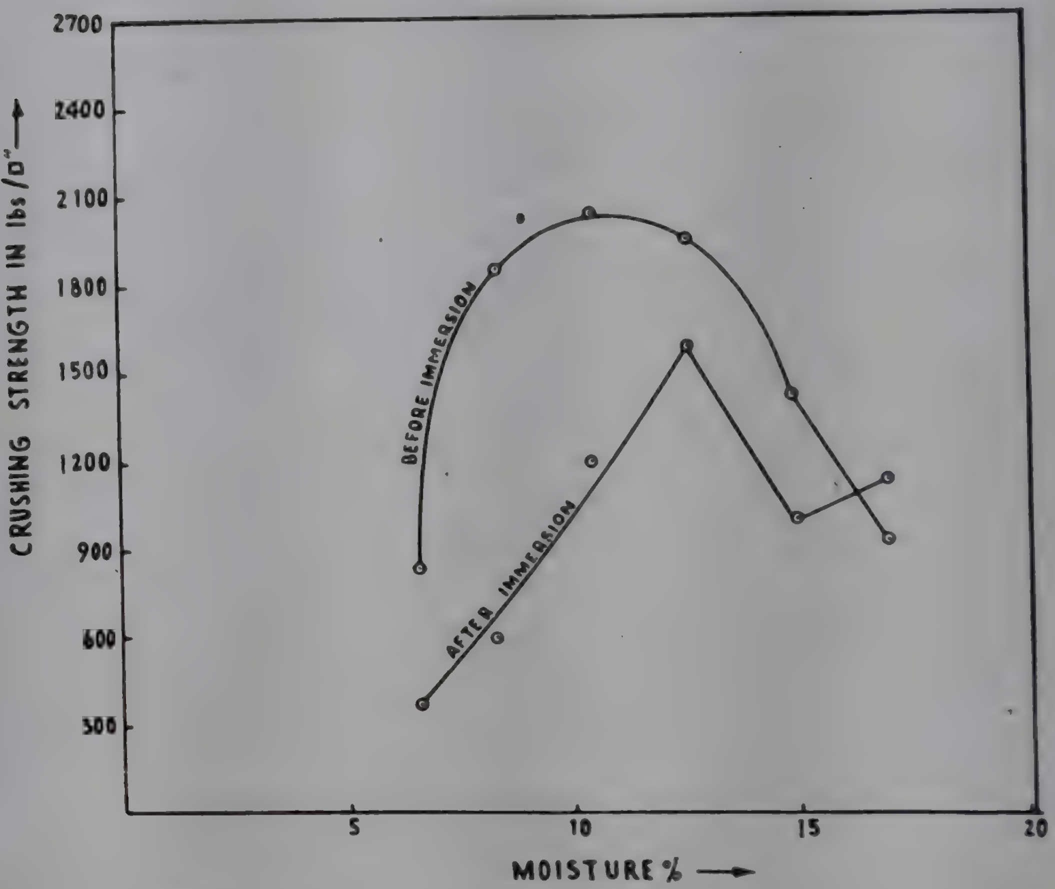

Fig. 7—South Arcot lignite preheated to 300°C.

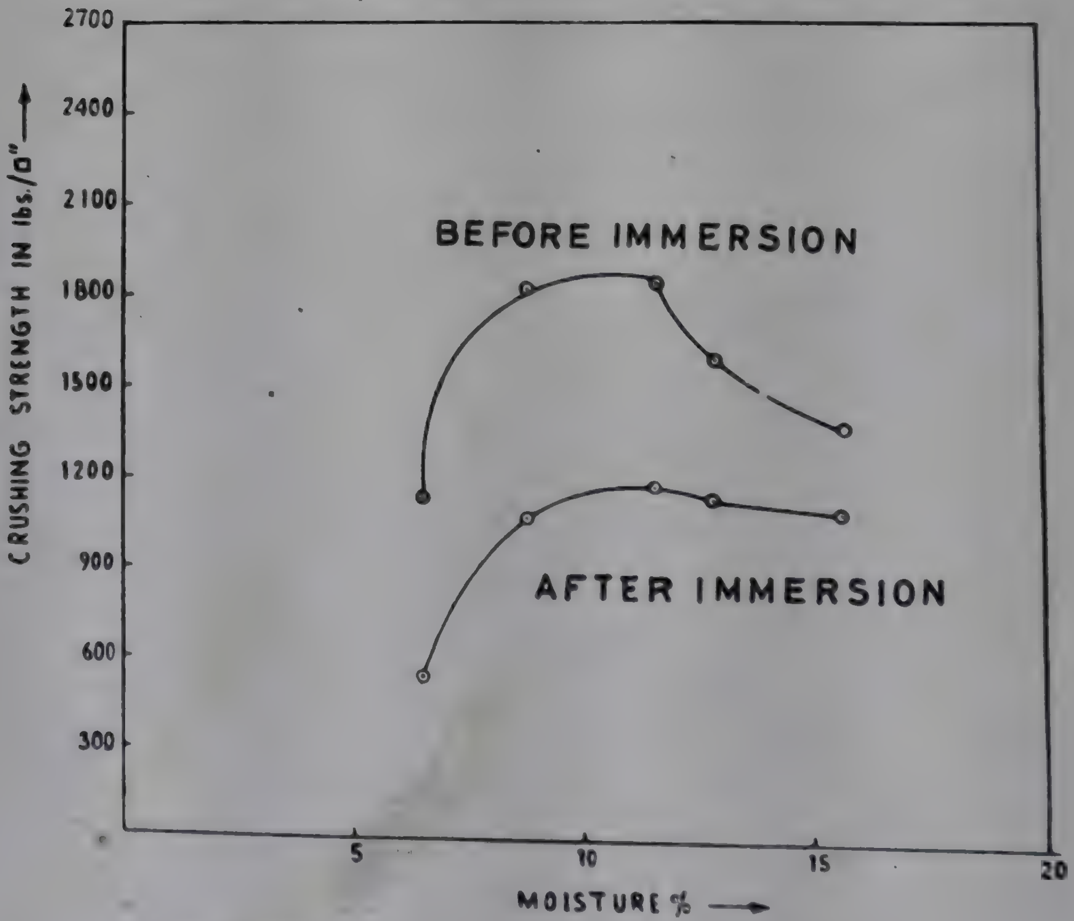

Fig. 8—South Arcot lignite preheated to 350°C.

TABLE 5—INFLUENCE OF HUMIC ACID AND BITUMEN ON BRIQUETTING PROPERTIES OF LIGNITE

Particulars of briquette*	Height of briquette	Crushing strength in lb./sq. in.	Water immersion test, Remarks
S. A. lignite	1 cm.	6054	Disintegrates
Humic acid only	do	5319	do
Humic acid-free S. A. lignite	do	6540	Does not disintegrate after 24-hr immersion
Bitumen-free S. A. lignite	do	5848	Disintegrates

*All the briquettes were made at 14·61 tons/sq. in. pressure and approximately 14% moisture.

briquettes from lignite, humic acid and bitumen-free lignite all disintegrate on immersion in water, the humic acid-free lignite briquettes (humin briquettes) do not disintegrate even after 24 hr immersion. Thus humin plays important part in imparting water-resistant properties. It is known[13] that the humin percentage increases with the rank of the fuel. It is the principal constituent of high rank lignite. There are several theories on the origin of humins. It was suggested that humins are formed by polymerization of humic acids[13], by the transformation of humic acids by decarboxylation, dehydration and formation of lactones; and that humins exist as separate entities at different stages of evolution. But the fact that lignite on heat treatment becomes water-resistant and that the humins are also water-resistant would lend support to the view that the humins are evolved from humic acid. Experiments on the functional groups in humins indicate that these contain almost the same percentage of carboxyl and hydroxyl groups as are necessary for hydrogen bond formation[14]. Therefore, to assume that humins are formed by decarboxylation of humic acids may not be true. What is more plausible is that humins are formed by the polymerization or condensation of humic acid, and that this, in some manner, imparts water-resistance. A better understanding of the phenomena is only possible when the structure of humins and humic acid are fully understood.

ACKNOWLEDGEMENT

The authors wish to acknowledge the help of Shri T. A. Subramanian in some portion of the experimental work and the analytical staff for the various analyses.

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DISCUSSION

Dr S. H. Zaheer: Our observations on the combustibility of briquettes made from lime-treated Kashmir lignite are not in agreement with those of the authors. We have done several experiments on the use of lime as binder and found that though these briquettes were strong, their combustibility was poor. This requires further discussion.

Dr M. S. Iyengar: Our method of lime treatment of lignite appears to be different from that adopted by D. K. Rao and coworkers, who have digested lignite with water and also with lime water at 80°C. before briquetting. I do not know what concentration of lime was used in their experiments. In our experiments, Kashmir lignite was air-dried to 10 per cent moisture content and mixed with 1 per cent lime water to give good consistency and then briquetted. The lime-treated lignite gave better shatter and American abrasion index.

In our experiments on combustion studies, the briquettes were introduced into a furnace at 600°C. and the rates of burning determined. At the end of the experiments practically no carbon was left. D. K. Rao and coworkers, seem to think that the ash fusion point is making all the difference. If this were so, how could South Arcot lignite whose ash has the same fusion range as that of Kashmir lignite give good burning properties. The fusion point of ash may not therefore be responsible for the difficulties in combustion.

Dr M. G. Krishna: The details of the procedure adopted in briquetting of Kashmir lignite and for combustion tests on the briquettes were already described in our paper. There are several references to show that a temperature of about 1200°C. is reached during combustion of solid fuels and is therefore, a critical range for the occurrence of incipient fusion of ash. During combustion of Kashmir lignite briquettes on open grates, it is likely that these critical temperatures are attained at different spots on the briquette surfaces, leading to fusion of ash particles and formation of an intervivous layer preventing diffusion of air into the core of the briquette, thereby restricting further combustion. In order to check this phenomenon, photomicrographs were prepared from sections of ash from burnt briquettes made of pure Kashmir lignite, and blends of the lignite with sawdust, charcoal and Kashmir anthracite. The ash from pure lignite briquette (Fig. 9) shows a dense crust on the outer surface and is hard to scratch with nail. This might be hindering easy penetration of air into the interior. On the other hand ash from briquettes made of 30 per cent sawdust

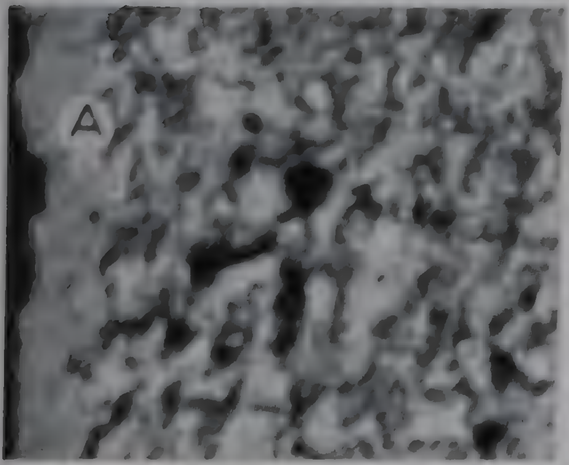

FIG. 9—SECTION OF LIGNITE BRIQUETTE ASH × 50. A: Fused ash surface

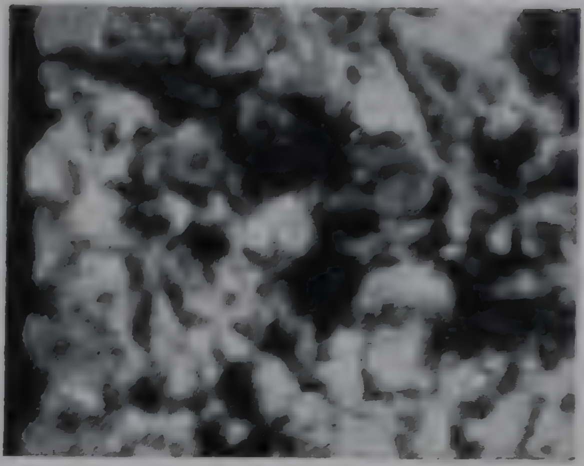

FIG. 10—SECTION OF LIGNITE SAWDUST (80/20) BRIQUETTE ASH × 50

and 70 per cent lignite (Fig. 10) does not have the continuous dense outer crust and has many voids. Examination under petrographic microscope showed that pure lignite ash had several glass particles indicating fusion has occurred. These particles were absent in ashes from blended briquettes.

Dr Iyengar referred to the good combustion of South Arcot lignite. It must be noted that this lignite has only 5·8 per cent ash whereas Kashmir lignite has 39 per cent ash. It therefore, appears that the high ash content and low fusion characteristics of the ash from Kashmir lignite may be responsible for the poor combustion of this lignite, particularly in ordinary domestic open grates which are not provided with chimneys to create sufficient draught.

Dr M. S. Iyengar: Since Kashmir lignite is of a very inferior type due to its high ash content, the design of ovens will have to be modified with suitable openings for primary as well as secondary air. There is no doubt that the fusion point is a factor in the easy combustibility of coals. But the rise in fusion point of lignite ash by 40°C. when it is mixed with anthracite is not going to make all the difference and is a debatable point.

Hot Briquetting of Indian Coals

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Indian coals can be briquetted at low pressures of 1-2 tons/sq. in. and at temperatures of the order of 100°-400°C. The briquettes obtained at higher temperatures burn more easily and produce less smoke. This advantage is particularly noticeable in the case of Kashmir lignite and sawdust blends. Preheating of coal or degassing improves the strength of the briquettes, the temperature of degassing being characteristic of the coal. Carbonization of blends of non-caking and weakly caking coal led to product suitable for metallurgical use.

In earlier papers[1-3] it was shown that all ranks of coal can be briquetted without binder at the moisture content corresponding to 60 per cent R. H. and 40°C. by application of pressures of the order of 8-10 tons/sq. in. Since within certain limits the effects of pressure and temperature are complementary, the possibility of binderless briquetting of coals at lower pressures, of the order of 1-2 tons/sq. in. was investigated by increasing the temperature of briquetting.

Several workers[4-8] studied the influence of temperature on the briquetting properties but in general all these tests were unsystematic in their exploration of the variable factors like time, temperature and pressure. McKenzie and coworkers[9] carried out a more detailed investigation on the binderless briquetting of coals. They successfully briquetted a lignite and a sub-bituminous coal without a binder by process involving the preheating of the coal for several minutes at temperatures of 400°-600°C. followed by agglomeration at pressures ranging from 2·5 to 39 tons/sq. in. for sub-bituminous coal and 12 tons/sq. in. for the lignite. Similar study of the influence of temperature on the briquetting properties of Indian coals has not so far been made.

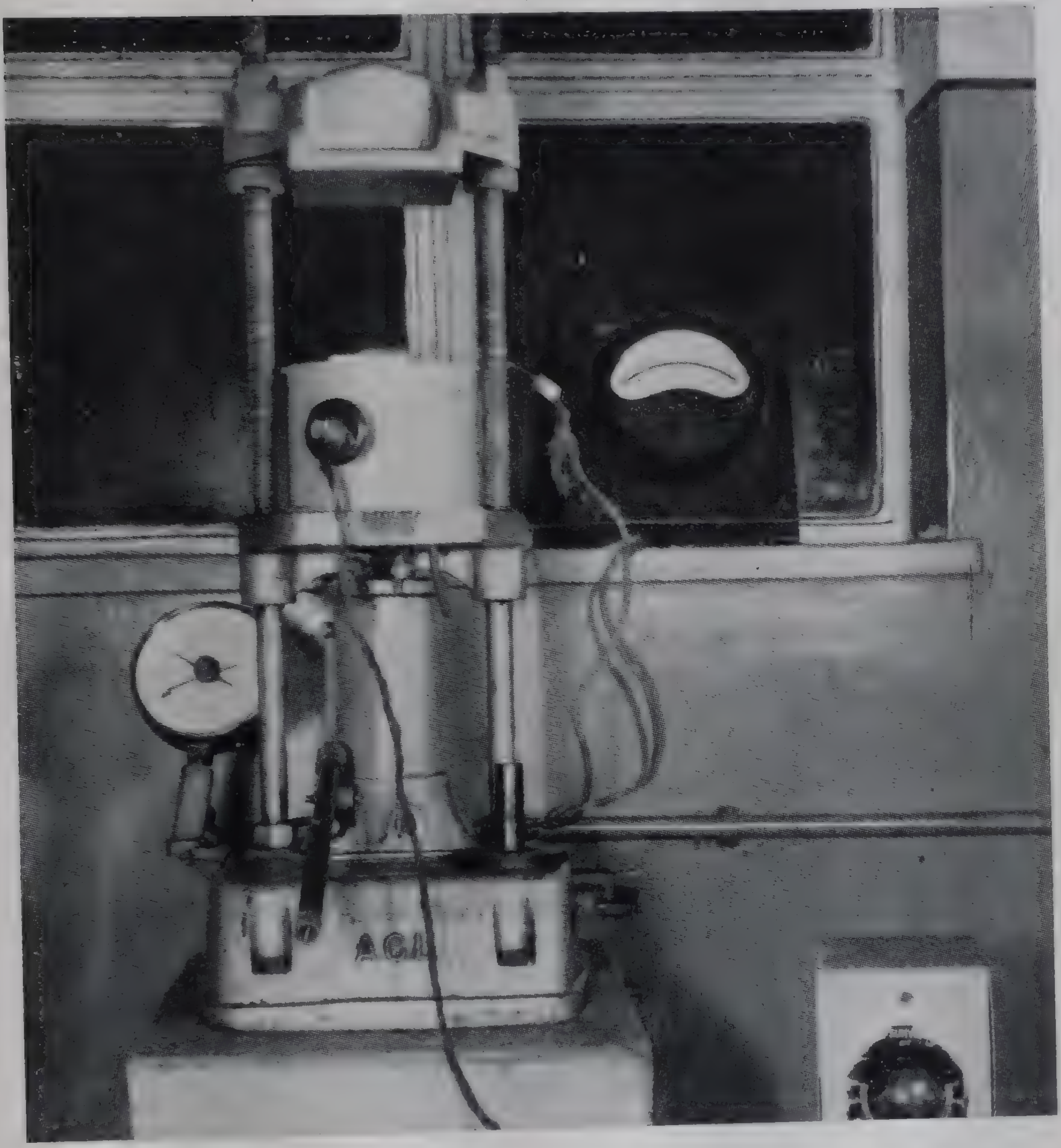

FIG. 1—MOULD FOR BRIQUETTING

EXPERIMENTAL PROCEDURE

Three coals of different ranks and two lignites were used in this study. Their analysis are given in Table 1.

Experiments on Kashmir lignite were carried out on samples crushed in stages to −6 mesh and −14 mesh B.S.S. In all other cases coals were crushed to −72 B.S.S. according to the standard method.

Kashmir lignite was briquetted in a 1·4 in. diam. mould while a 1 in. diam. mould was used for the rest. The die and briquetting assembly are shown in Figs. 1 and 2. An electrically heated circular furnace surrounded the die. The temperature was measured with a thermocouple placed in the

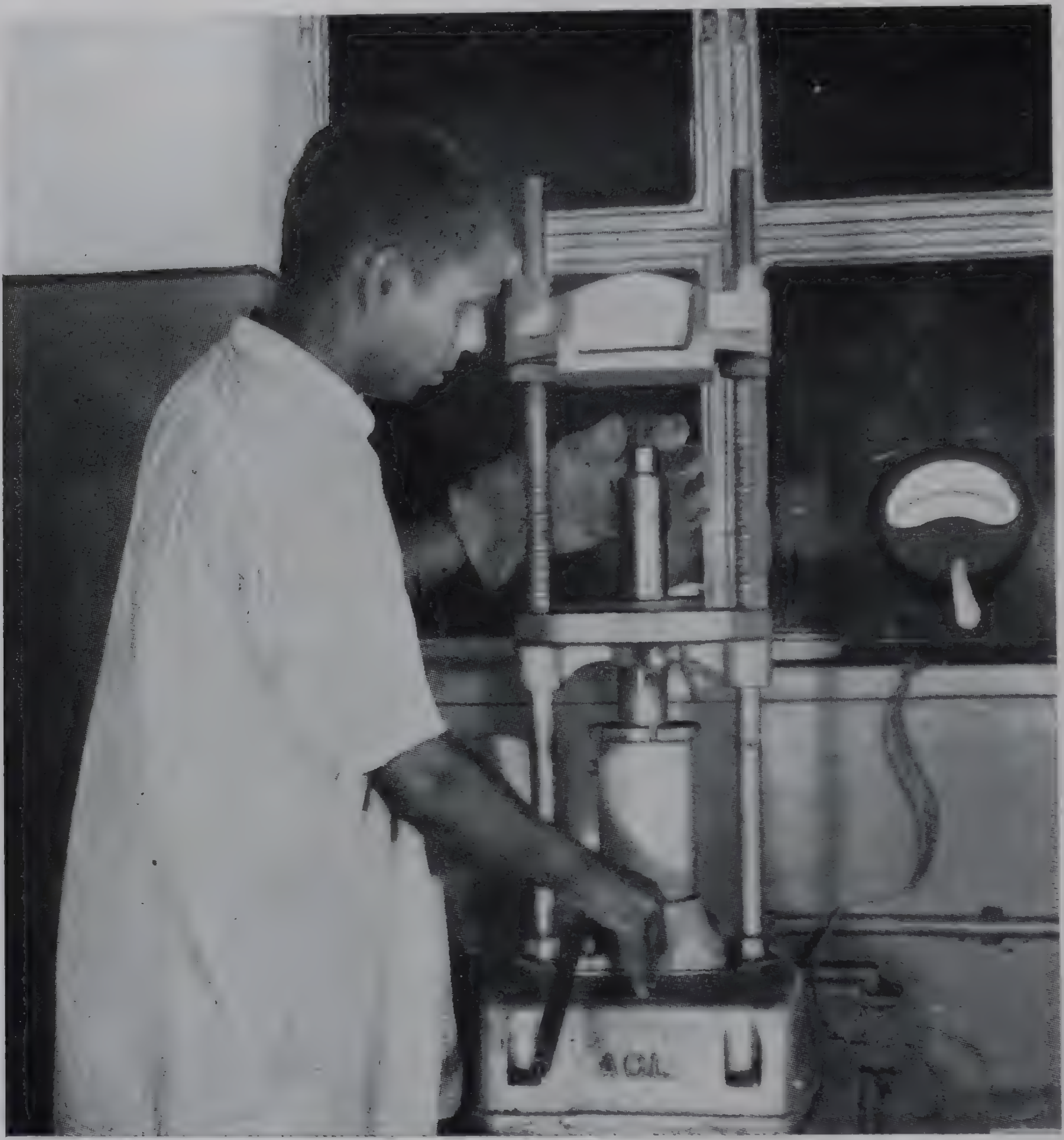

FIG. 2—BRIQUETTING ASSEMBLY

die. The furnace was maintained at the desired temperature by means of a Variac voltage regulator.

The amount of coal taken was adjusted to give a briquette of the same height at any given temperature and varied 15-19 g. The coal sample was placed in the die, preheated to the desired temperature and maintained there for 15 min. The steel plunger was then inserted and the pressure applied immediately. The retention or briquetting time was 3 min.—1 min. at full load and 2 min. for the slow release of pressure and taking out the briquette. The briquettes obtained were tested for compression strength in a universal compressing testing machine as described earlier[1].

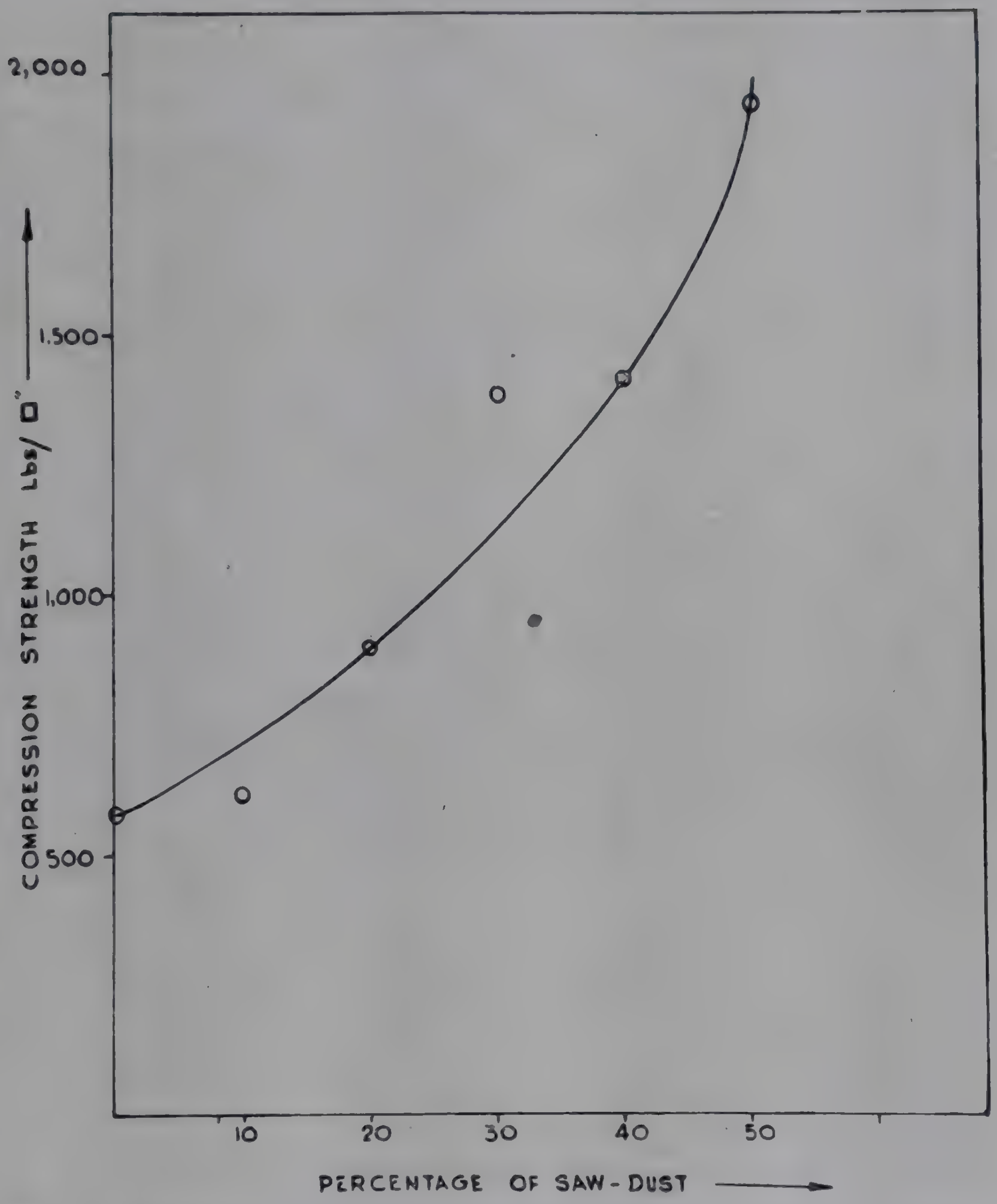

FIG. 3—INFLUENCE OF SAWDUST ON THE STRENGTH OF KASHMIR LIGNITE BRIQUETTES

RESULTS AND DISCUSSION

Kashmir Lignite. Kashmir lignite has a very high mineral matter content (ash 49 per cent) and hence a low calorific value. The mineral matter is very intimately mixed with the lignite and cannot be separated by any of the conventional methods. As the Kashmir valley abounds in wood and saw mills, it was thought worthwhile to investigate the possibilities of blending the lignite with sawdust prior to briquetting. Fig. 3 illustrates the results obtained by briquetting different lignite-sawdust ratios at 5 tons/sq. in. (sieve size 6 mesh B.S.S.). A general improvement in the briquette strength was observed with increase in the proportion of sawdust. But these briquettes suffered from a serious disadvantage. During combustion

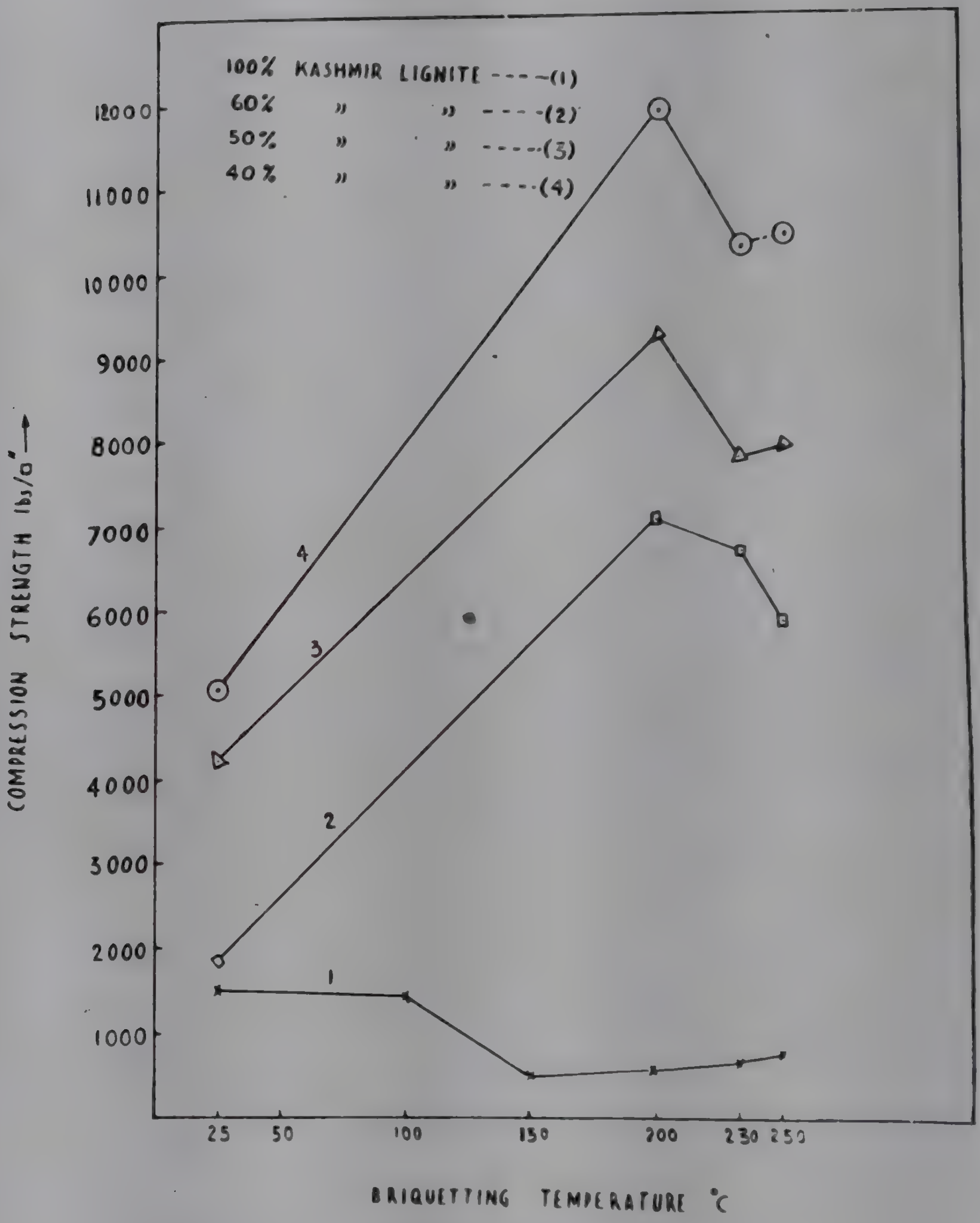

FIG. 4—HOT BRIQUETTING OF KASHMIR LIGNITE SAWDUST

the sawdust burnt out preferentially and the residue could burn only with difficulty. Further, the briquettes disintegrated completely on immersion in water.

It was therefore decided to study the influence of temperature on the briquetting and combustion properties of Kashmir lignite-sawdust blends. In this case the pressures used were 6·5 tons/sq. in. and sieve size —14 mesh B.S.S. The results obtained are presented in Figs. 4 and 5. While the Kashmir lignite by itself was not very much influenced by temperature, the effect on the blends was significant. In general there was an increase in the strength of the briquette with increase in the proportion of sawdust and increase in temperature. It is remarkable that for all the different lignite-sawdust

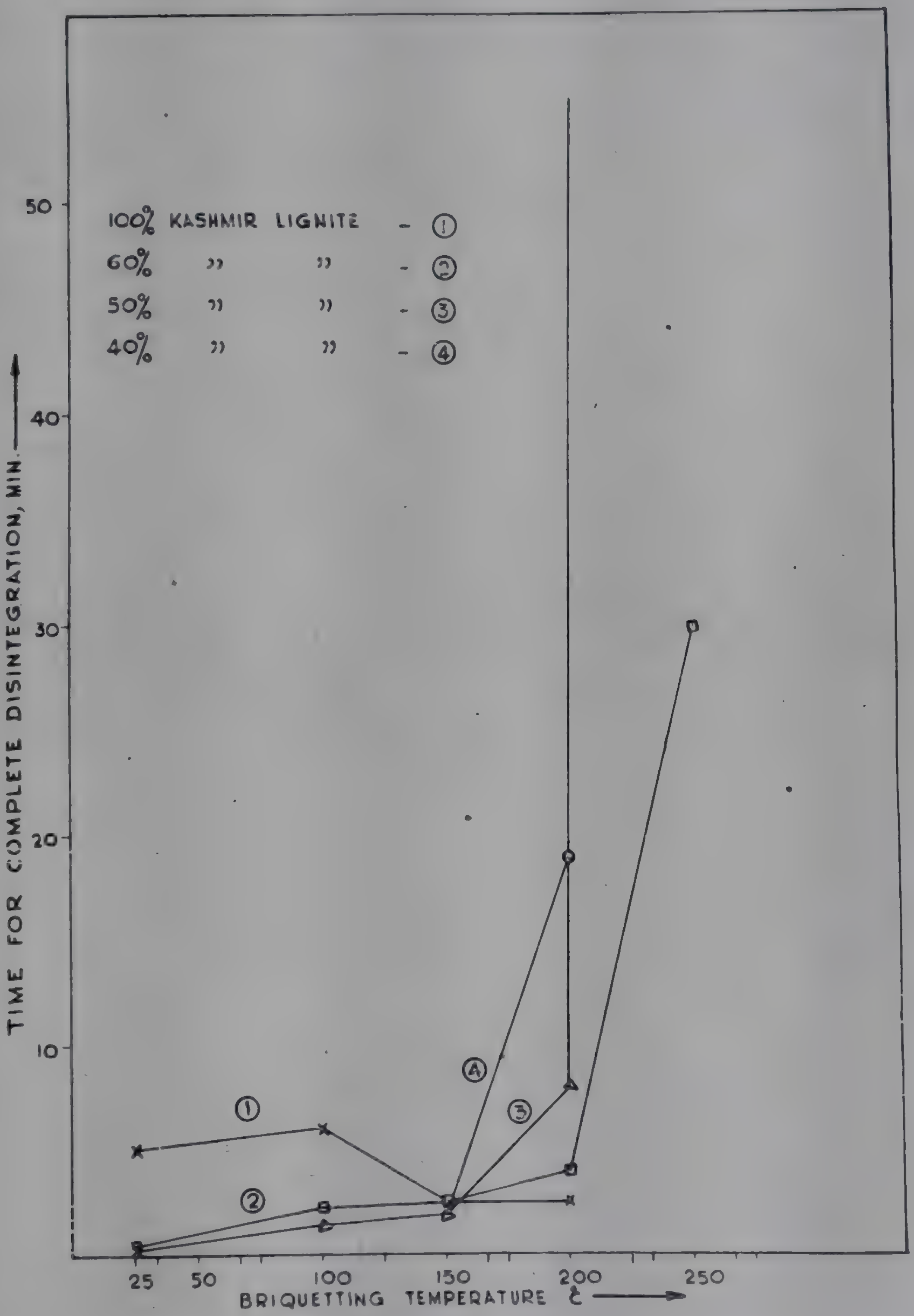

Fig. 5 – Water resistance of hot briquettes made with Kashmir lignite and sawdust

blends studied, the maximum strength was obtained at the briquetting temperature of 200°C. A blend of 40 per cent lignite and 60 per cent sawdust gave a briquette of crushing strength 12000 lb./sq. in. when briquetted at 200°C., the highest ever recorded by us. Remarkable improvement in water resistance (Fig. 5) and combustion characteristics were observed for these briquettes and there was no preferential burning of sawdust.

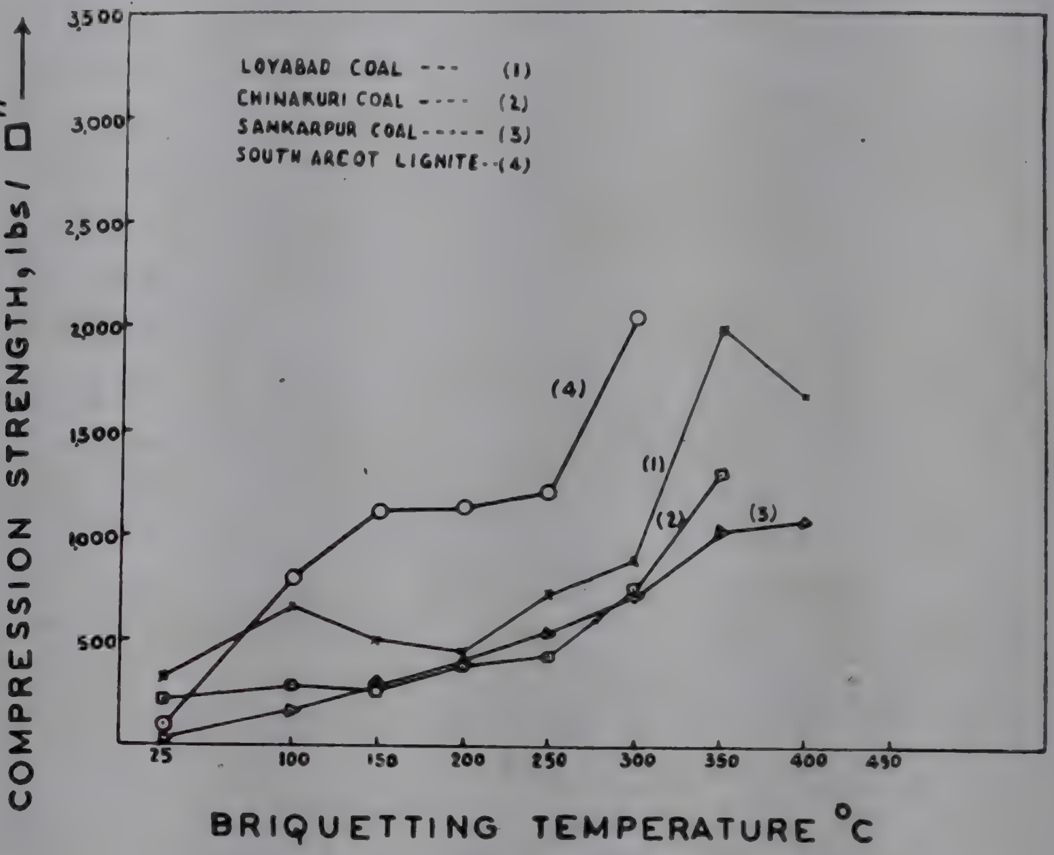

FIG. 6—Hot briquetting of different rank coals

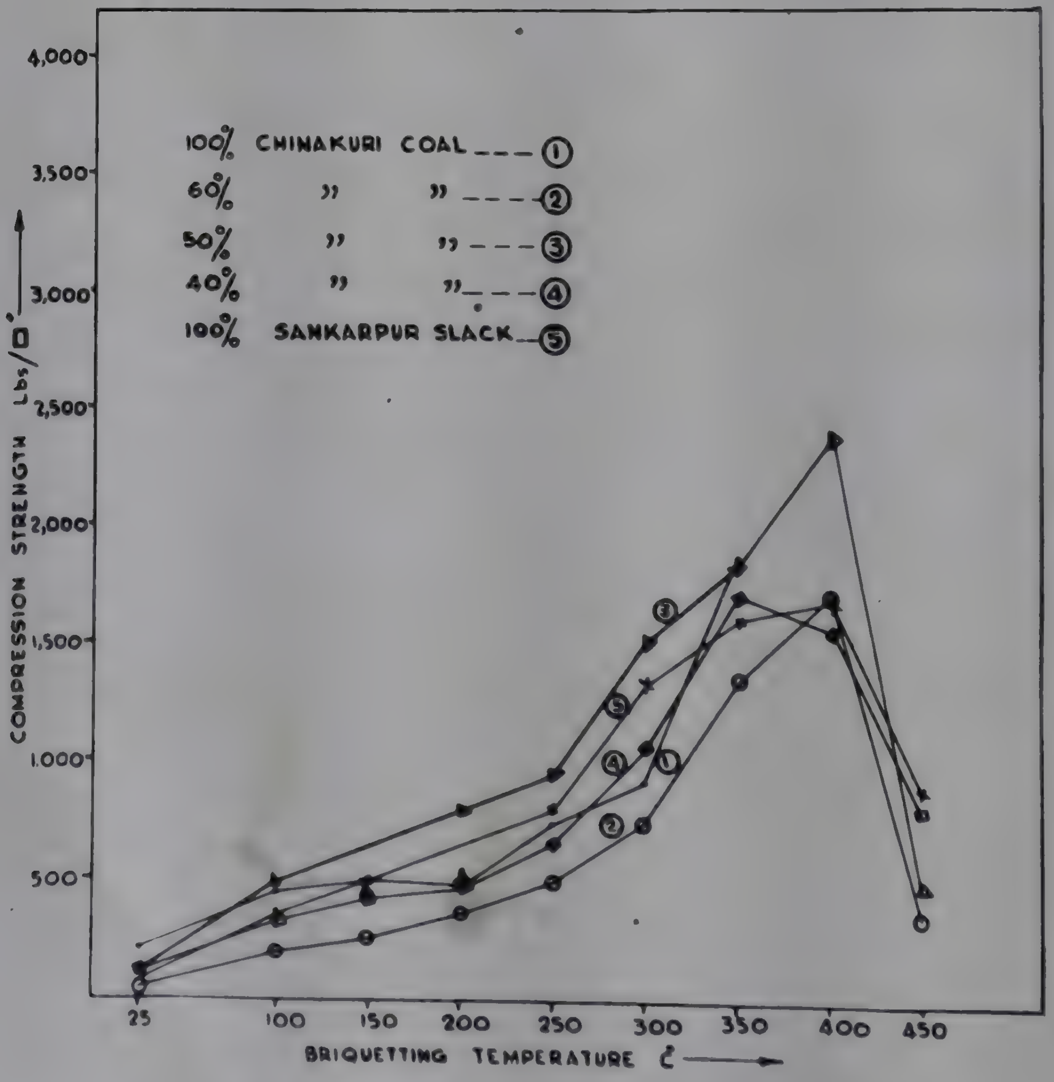

FIG. 7—Hot briquetting of Chinakuri-Sankarpur blends

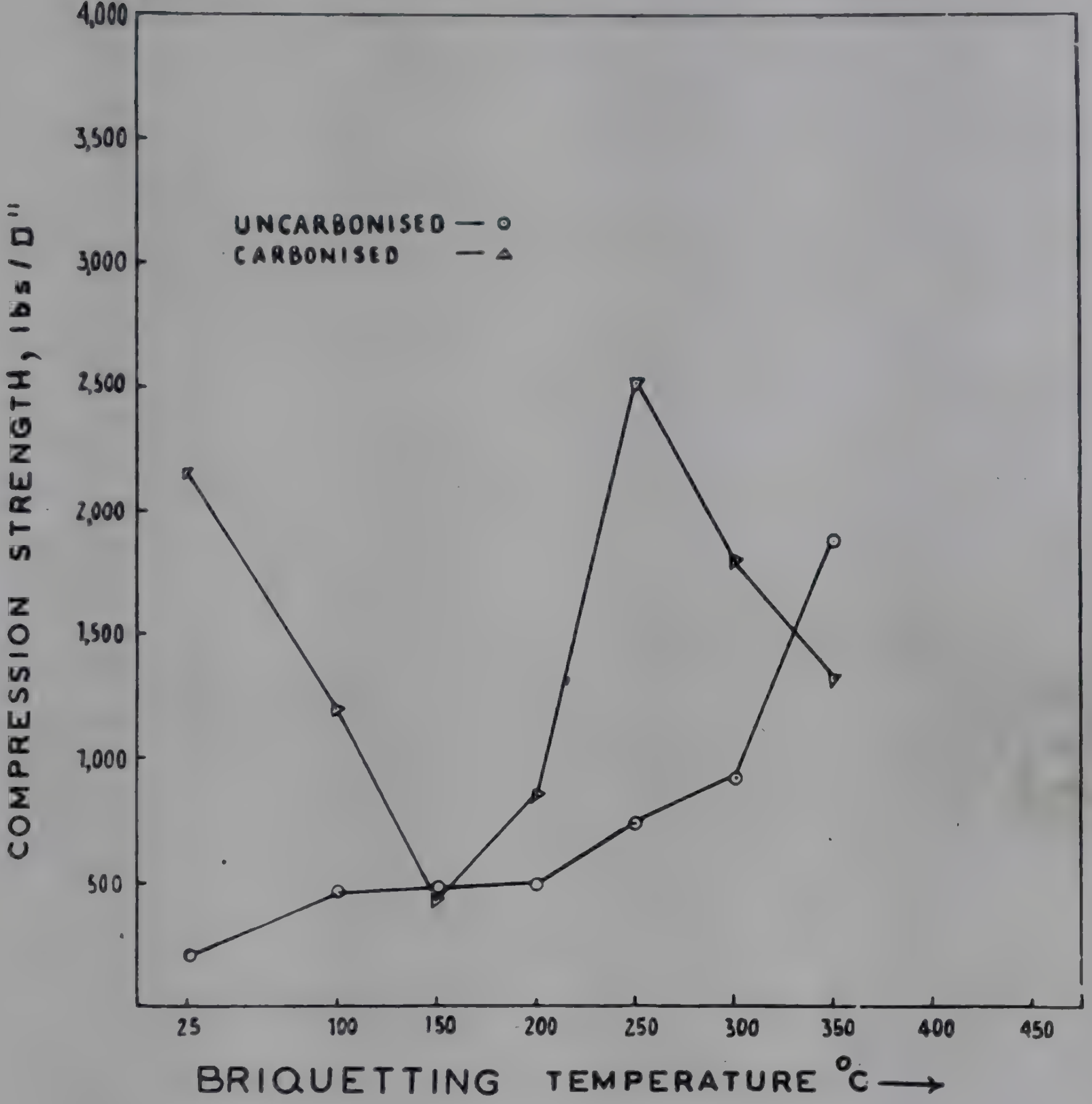

FIG. 8—HOT BRIQUETTING OF CHINAKURI COAL AT DIFFERENT TEMPERATURES AND CARBONIZED AT 900°C.

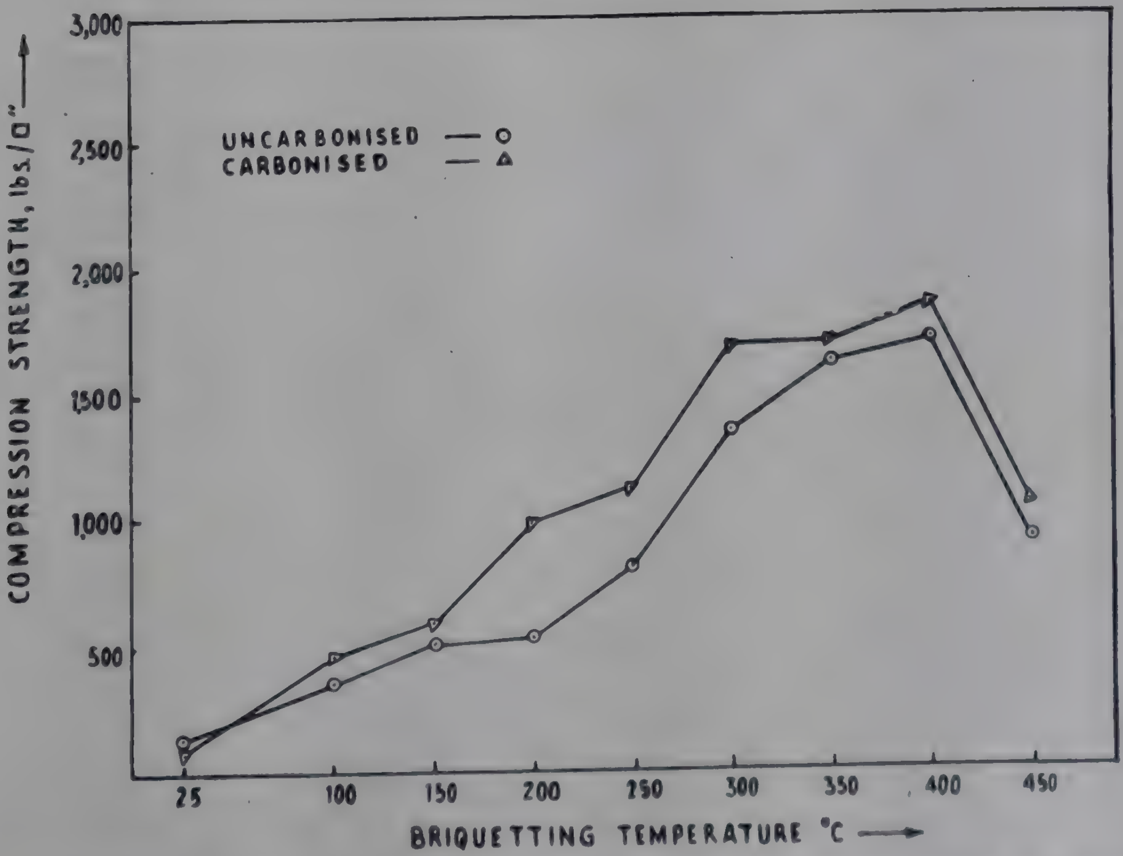

FIG. 9—HOT BRIQUETTING OF SANKARPUR COAL AT DIFFERENT TEMPERATURES AND CARBONIZED AT 900°C.

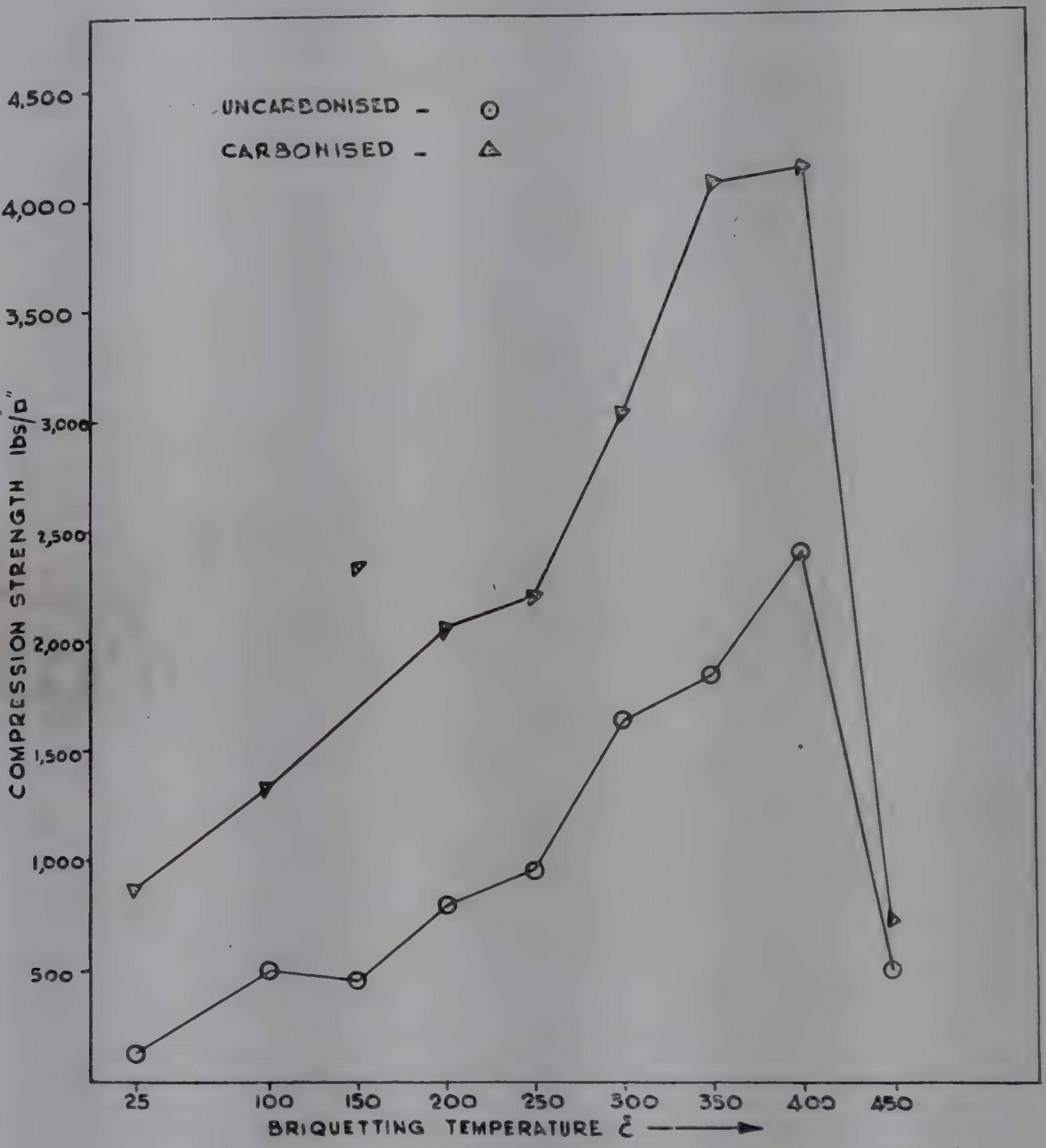

FIG. 10—HOT BRIQUETTING OF CHINAKURI-SANKARPUR BLEND (1:1) AND CARBONIZED AT 900°C.

"Hot Briquetting" of Coals of Different Ranks. Four coals of different ranks lignite, semi-bituminous, high volatile bituminous and a coking coal—were briquetted at different temperatures and 5820 lb./sq. in. pressure. The results, presented in Fig. 6, show an increase in strength with increase in the temperature of briquetting. South Arcot lignite could not be briquetted at a temperature higher than 300°C. due to profuse evolution of gases resulting in a tendency for "explosions", but the strength of South Arcot lignite briquettes was higher than that of other coals. With other coals maximum strength was obtained at about 350°C., and the effect of rank was not very significant. While South Arcot lignite behaved normally,

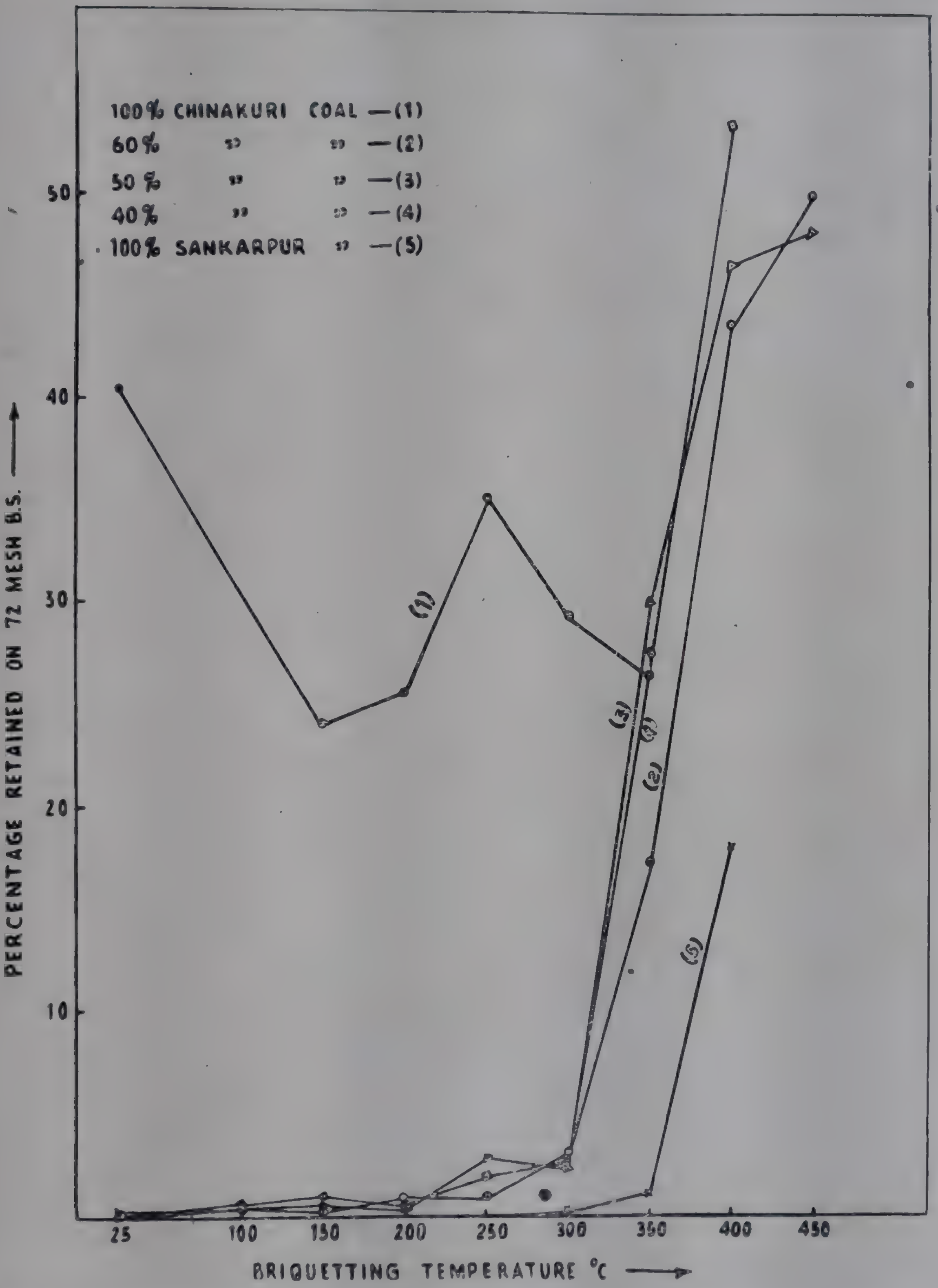

FIG. 11—MICROSTRENGTH INDEX OF CARBONIZED BRIQUETTES OF CHINAKURI AND SANKARPUR COALS AND THEIR BLENDS

Kashmir lignite was not affected much by temperature which may be attributed to the high mineral matter content of the latter.

Blends of a High Volatile Weakly Caking and High Volatile Non-caking Coals. Sankarpur and Chinakuri coals from the Raniganj coalfield were blended in different proportions and hot briquetted at

TABLE 1—ANALYSES OF DIFFERENT RANK COALS AND SAWDUST

	% ON AIR-DRIED BASIS				% ON DRY MINERAL-MATTER-FREE BASIS				
	Moisture	Ash	V.M.	F.C.	C	H	S	N	O
South Arcot lignite	23·0	5·8	39·8	31·4	71·99	4·98	0·99	0·72	21·32
Sankarpur slack coal	5·5	13·1	34·1	47·3	80·74	5·12	0·52	1·85	11·77
Chinakuri coal	1·9	15·1	36·0	47·0	84·6	5·9	0·3	2·4	6·8
Loyabad coal XV seam	1·3	18·8	22·3	57·6	90·4	5·1	0·7	2·0	1·8
Kashmir lignite	17·6	39·7	27·4	15·3	67·89	5·29	0·96	1·96	23·90
Sawdust	9·2	7·9	71·1	11·8	55·25	5·38	0·04	0·15	39·18

different temperatures (Fig. 7). Blends of 50 : 50 Sankarpur and Chinakuri coals gave a stronger briquette up to a briquetting temperature of 400°C. than the individual coals and the maximum strength was obtained at 400°C. with this blend.

Influence of "Degassing". To study the effect of "degassing", the coal samples were taken in a retort and inserted into an electrically heated furnace. The furnace was heated from room temperature to the desired temperature and the sample maintained at that temperature for 5 min. before removal. The samples were cooled to room temperature and briquetted at the desired temperature. The results obtained are compared in Table 2 with those obtained with "undegassed" samples. In all cases the beneficial effect of "degassing" is noticeable; for instance, Sankarpur coal when briquetted at 400°C. gave a briquette of 1083 lb./sq. in. compression strength. But when this coal was degassed at 100°C. and briquetted, the strength increased to 2082 lb./sq. in. The temperature of degassing at which maximum benefit accrued varied with the nature and rank of coal. While Sankarpur coal gave maximum strength on degassing at 100°C. and briquetting at 400°C., Loyabad coal gave it by degassing at 500°C. and briquetting at 400°C. In certain cases degassing helped in the formation of briquettes as in the case of South Arcot lignite where the difficulty in briquetting was eliminated by degassing the lignite at 400°C. prior to briquetting at the same temperature (Table 2).

Influence of High Temperature Carbonization. The briquettes were inserted in an electrically heated tubular furnace and heated from room temperature to 900°C. at the rate of 5°C./min. and maintained at 900°C. for 2 hr before discharging. On cooling they were tested for their compression strength. The relative strength of the carbonized briquettes was determined by the microstrength apparatus[4]. For this purpose the briquettes were crushed to −14 +25 mesh B.S.S. and rotated in a steel

TABLE 2—INFLUENCE OF "DEGASSING" ON THE HOT BRIQUETTING OF COALS

(Briquetting pressure: 5,820 lb./sq. in.)

	Briquetting temperature	Compression strength, lb./sq. in. at degassing temperatures				
		Normal	100°C.	300°C.	400°C.	500°C.
South Arcot lignite	R.T.	94	137 F.W.R.	117 F.W.R.	88 F.W.R.	13 F.W.R.
	100°C.	793	..	805 D	..	209 F.W.R.
	300°C.	2,045	1,505 D	2,487 D	2,208 D	834 D
	400°C.	a	a	a	2,461 W.R.	1,861 W.R.
	500°C.	a	a	a	a	a
Sankarpur coal	R.T.	29	66 D	15 D	4 D	2 D
	100°C.	177	..	197 D	..	16 D
	300°C.	742	854 W.R.	765 W.R.	495	216 F.W.R.
	400°C.	1,083	2,082 W.R.	1,905 W.R.	1,086 W.R.	802 W.R.
	500°C.	a	a	a	a	1,303 W.R.
Chinakuri coal	R.T.	217	141 W.R.	118 W.R.	104 W.R.	84 W.R.
	100°C.	280	..	300 W.R.	..	116 W.R.
	300°C.	747	767 W.R.	820 W.R.	264 W.R.	326 W.R.
	400°C.	..	2,681 W.R.	1,752 W.R.	2,105 W.R.	1,505 W.R.
	500°C.	..	a	a	a	1,665 W.R.
Loyabad coal	R.T.	314	394 W.R.	251 W.R.	177 W.R.	146 W.R.
	100°C.	..	..	430 W.R.	..	402 W.R.
	300°C.	884	838 W.R.	777 W.R.	365 W.R.	710 W.R.
	400°C.	1,683	2,237 W.R.	2,414 W.R.	2,752 W.R.	2,954 W.R.
	500°C.	a	a	a	a	984 W.R.

W.R.—Water Resistant; D—Disintegrates when immersed in water; F—Floats on water; R.T.—Room Temperature; a—Briquettes could not be made.

tube at 25 r.p.m. for 32 min. The products were screened on 25 mesh B.S.S. and 72 mesh B.S.S. and the percentage retained was taken as the microstrength index.

The results presented in Figs. 8-11 show that the hot briquettes from Chinakuri or Sankarpur coals alone did not show any marked improvement in strength when carbonized at 900°C. but their blends (50 : 50) briquetted at 350°-400°C. exhibited almost a two-fold increase in strength. This is also reflected in their microstrength.

GENERAL

McKenzie and coworkers[9] postulate that the mechanism of hot briquetting without binder is governed by the types of tar released at a given temperature (400°-600°C.)—the heavier tar fractions producing the proper bond, and at higher temperatures these tars are driven out of the system. They also explain the beneficial effect of "degassing" by assuming that during this stage, tars suitable for bonding are produced on the surface of the particles and in sufficient amount. It is difficult to accept this explanation, for, if heavier fraction of the tar alone is responsible for imparting strength then briquetting temperatures below the decomposition temperature of coal should not have any beneficial effect on the strength of the briquette. But actually, both lignite and semi-bituminous coal show marked improvement in strength on briquetting at temperatures below their decomposition temperatures (Table 2).

The beneficial effect of "degassing" cannot likewise be explained in terms of tar, for, in the case of Sankarpur coal, maximum benefit of "degassing" occurs at 100°C. which is well below its decomposition temperature.

A more likely explanation is that during normal briquetting the air or occluded gases form air pockets which hinder the particles from coming near each other. On "degassing", these pockets and the cushioning effect are eliminated resulting in improved strength. At higher temperature, above 400°C. tar may also be acting as a binding agent.

ACKNOWLEDGEMENT

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DISCUSSION

Dr M. G. Krishna: (1) It was stated that the beneficial effect of 'degassing' below 400°C. was more due to the expulsion of occluded gases than due to formation of tar on the surface of coal particles. It seems that this explanation may not fully hold good in the case of mixtures of sawdust and coal because pyrolysis of woody material leading to formation of liquid products begins at 100°C. and is very fast at 200°C. (2) The increase in compression strength with increase in sawdust content of a blend with Kashmir lignite at 25°C. (**Fig.** 4) is contrary to our observation.

Dr M. S. Iyengar: (1) There was a two-fold rise in the strength of briquettes from Sankarpur coal prepared at 100°C. compared to that at 25°C. No decomposition can be expected to set in at 100°C. (2) It will be seen from Fig. 3 that there is a continuous increase in strength with increase in sawdust content.

Pilot Plant Investigations on the Briquetting and Carbonization of South Arcot Lignite

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Neyveli

Pilot plant investigations on briquetting and carbonization of South Arcot lignite using Parry dryer, Glomera extrusion press and Parry carbonizer and the modifications incorporated in the design of the plant are described. The influence of grain size of lignite, moisture content, size of briquettes, rate of heating and temperature of carbonization on the physical properties of briquettes and the effect of modifications in the design of the plant are discussed.

Inadequate supply of fuels has been one of the reasons for the delay in the industrial and agricultural development of Madras State. The limited water resources have already been harnessed almost to the full; and the State has therefore to depend on coal from Singareni or Jharia. The discovery of lignite at Neyveli in South Arcot can largely meet this deficiency and provide a base for the large scale development of power, fuel and other industries in the area. Till now, lignite reserves have been proved in an area of 100 sq. miles and are estimated at 2000 million tons[1]. The great paucity of domestic fuels, increasing costs of charcoal and the adverse effects of deforestation on soil conservation and food production need little mention.

The Neyveli Lignite Corporation Limited have planned an integrated scheme for the development of lignite resources. The first stage of development of the Project consists of:

(*a*) An open cut mine to produce 3·5 million tons of lignite per annum to be increased to 6·00 million tons by the end of the Third Five Year Plan period.

(*b*) A thermal station with an installed generating capacity of 250 M.W. to be stepped up to 400 M.W. by the end of the Third Five Year Plan period.

(*c*) A fertilizer plant for producing 152,000 tons of urea (70,000 tons of nitrogen) per annum by the total recycle process.

(*d*) A briquetting and carbonization plant to produce 380,000 tons of carbonized briquettes per annum and includes units for processing liquid products.

(*e*) A clay washing plant to produce 6,000 tons per annum of high grade white clay.

Laboratory tests[2–6] have indicated that lignite is of good quality with low ash and sulphur, easily briquettable without binder and ideally suited for carbonization. A pilot briquetting and carbonization plant has also been obtained with T.C.M. aid, and installed to study the briquetting and carbonization characteristics of the lignite.

DESCRIPTION OF THE PLANT

The pilot plant consists of:

(*a*) A coal preparation section.

(*b*) A Parry dryer for drying lignite in an entrained state by hot inert gases.

(*c*) An extrusion press.

(*d*) A carbonizer designed by United States Bureau of Mines.

(*e*) Tar distillation equipment.

The coal preparation section has a hammer mill with a throughput of 5 tons/hr. The dryer can handle 2·5 tons of raw crushed lignite per hour reducing the moisture content from 56 per cent to 10 per cent. The 'Glomera' briquetting press designed by M/s Pawert A. G. of Switzerland, can make briquettes of two sizes: (*a*) 65 mm. diam. (capacity: one ton/hr) and (*b*) 35 mm. (capacity: 500 kg./hr).

The carbonizer was designed to carbonize 150 to 250 kg. of raw briquettes per hour. The carbonizer as designed could not be operated continuously as it resulted in too much fines. Also the quality of gas was poor to be used as fuel. Practically no tar was recovered. Most of the tests had, therefore, to be carried in batch runs of about 500 kg. to 1 ton each.

DESCRIPTION OF RUNS

Forty-five runs on the dryer, 91 runs on the briquetting press and 63 runs on the carbonizer have so far been made since the plant was commissioned in May 1958.

The aim of the investigations was to find out the optimum conditions for drying, briquetting and carbonization to produce good, sufficiently strong carbonized briquettes for use as domestic fuel in place of charcoal. The results of the study on the effect of different variables like of grain size, moisture, temperature of carbonization, etc. have already been reported[7] and were found to be in conformity with earlier findings[2-6].

MODIFICATIONS INCORPORATED IN THE PILOT PLANT

Preparation Section. Laboratory scale experiments indicated that best briquettes for carbonization could be produced by using as fine and as dried a material as possible. This necessitates very high briquetting pressures but is limited in commercial practice by the choice of materials and economics of briquetting. Recent work has shown that briquettes could be produced better from a material of 0-2 mm. than 0-1 mm.[8] The hammer mill provided produced too many fines which on drying further reduced in size. This material could not be briquetted with the press supplied.

This difficulty was overcome by changing the number, size and shape of the hammers. Further, screens were eliminated and speed of the mill reduced from 3000 r.p.m. to 1450 r.p.m. The analysis of lignite and size reduction obtained before and after incorporating the changes are given in Tables 1 and 2.

TABLE 1—ANALYSIS OF SOUTH ARCOT LIGNITE

Proximate analysis	%
Moisture	51·0—56·0
Ash	2·2— 3·3
Volatile matter	22·4—24·9
Fixed carbon	19·1—20·6
Ultimate analysis	
Carbon	29·5—33·6
Hydrogen	2·1— 2·4
Nitrogen	0·24—0·29
Sulphur	0·3 —0·5
Oxygen	8·6 —9·3
Ash	2·2 —3·3
Moisture	51·0—56·0
Calorific value	
Gross, kcal./kg.	2560—3165
Net, kcal./kg.	2307—2902

TABLE 2—SIZE ANALYSIS OF CRUSHED RAW LIGNITE AND CORRESPONDING ANALYSIS OF DRIED LIGNITE

Sieve No. Tyler	Before changing hammer and reducing motor speed			After changing hammer and reducing motor speed		
	Crushed raw lignite	Dried lignite		Crushed raw lignite	Dried lignite	
		Sample I	Sample II		Sample I	Sample II
	Cumulative weight, %	Cumulative weight, %	Cumulative weight, %	Cumulative weight, %	Cumulative weight, %	Cumulative weight, %
4	10·2	..	..	13·4	..	..
8	28·8	..	..	31·5	1·8	2·4
16	54·6	3·2	4·8	58·6	7·8	7·2
28	60·4	15·8	18·6	68·4	23·8	25·4
48	72·6	37·2	36·4	79·4	42·8	42·0
60	76·8	42·1	43·6	82·4	52·4	54·0
80	80·2	50·1	49·8	87·3	68·2	68·4
100	84·8	56·4	56·4	93·3	78·1	80·2
200	89·8	66·1	64·3	96·6	82·4	83·6
−200	10·2	33·9	35·7	3·4	17·6	16·4
Moisture, %	50·3	11·7	10·8	50·0	11·5	11·2

Many theories[9–13] have been advanced regarding the role of moisture in briquetting of lignite, but none of them explains satisfactorily the increase in strength of briquettes with the final temperature of carbonization. A probable explanation is that initially the briquettes are sustained by hydrogen bonds and by the cohesion forces emanating from the plastic flow of coal[14]. With increase in temperature, the weak hydrogen bonds are ruptured (marked by decrease in strength) but on further heating the tar given out acts as binder. Further increase of temperature cokes the pitch in the tar and forms a strong cementing layer.

Carbonization Section. The size of raw briquettes plays an important role in the production of lumpy char. The smaller the size the lumpier is the char. The carbonized briquettes are sustained by shrinkage strength and the stress causing the fissures is minimum with the least temperature gradient between the surface and the core of the briquettes.

The significance of slow rate of heating in the initial stages of carbonization cannot be over emphasized.

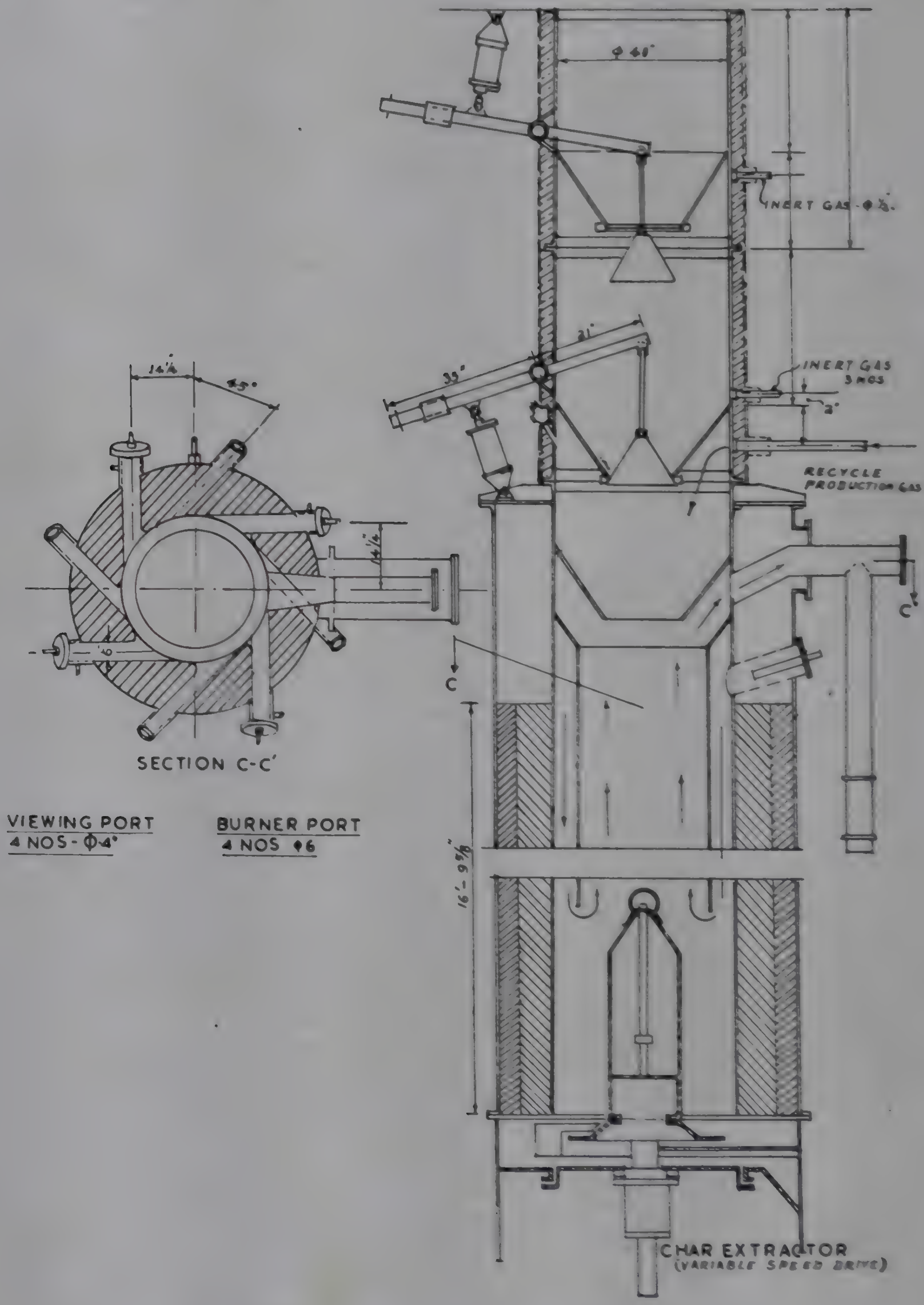
Φ 40"
INERT GAS - Φ ½"
31"
33"
14¼"
45°
INERT GAS 3 NOS
2"
RECYCLE PRODUCTION GAS
C'
C
14¼"
SECTION C-C'
VIEWING PORT 4 NOS - Φ4"
BURNER PORT 4 NOS Φ6
16'-9⅝"
CHAR EXTRACTOR (VARIABLE SPEED DRIVE)

Fig. 1—Carbonizer assembly and modifications

Fig. 1 gives the details of the Parry carbonizer and the modifications. The carbonizer is heated by producer gas. The hot gases travel downward and enter the charge at the bottom and travel upward counter-current to the briquettes moving downwards. The briquettes are contained in a stainless steel retort. The briquettes are therefore heated both directly

TABLE 3—INFLUENCE OF MODIFICATION IN THE DESIGN OF CARBONIZER ON THE YIELD AND QUALITY OF PRODUCTS

	BEFORE MODIFICATION		AFTER MODIFICATION
	Continuous run	Batch run	Continuous run
Raw briquettes			
Moisture, %	11·4	12·2	11·2
Ash, %	6·2	6·8	6·4
Volatile matter, %	42·4	42·8	42·4
Fixed carbon, %	40·0	38·2	40·0
Compression strength, kg./sq. cm.	112	110	115
Carbonized briquettes			
Moisture, %	1·8	1·4	1·6
Ash, %	13·8	14·2	14·0
Volatile matter, %	16·8	13·4	15·2
Fixed carbon, %	67·6	71·0	69·2
Compression strength, kg./sq. cm.	98·0	120·0	110·0
Tumbler index +20 mm.	42·6	92·4	84·8
Shatter test +20 mm.	54·2	76·4	70·4
Size analysis (cumulative weight, %)			
+40 mm.	10·0	62·4	40·0
+25 mm.	42·0	78·0	58·0
+20 mm.	54·0	78·4	71·0
+12 mm.	65·0	87·4	83·0
Tar yield, %	1·0	Nil	7·8
Gas analysis, %			
Carbon dioxide	20·4		18·2
Illuminants	0·2		0·6
Oxygen	Nil	Not analysed	Nil
Carbon monoxide	10·8		18·6
Hydrogen	5·6		12·4
Methane	4·2		9·2
Nitrogen (by difference)	58·8		41·2
Calorific value, kcal./Nm³	887		1794

and indirectly (through the retort). Inert gas is introduced into the charging hoppers to prevent any intake of air into the carbonizer.

The raw briquettes enter the carbonizer at the zone of maximum temperature and disintegrate by the sudden escape of water vapour. Since the products of carbonization leave the retort near the zone of maximum temperature, tar is cracked and is not recovered in the condensation unit. The volatile products of carbonization are greatly diluted by the water vapour from drying of briquettes and the quality of gas is too poor to be used as fuel.

Batch runs had, therefore, to be made.

TABLE 4—PROPERTIES OF LOW TEMPERATURE TAR FROM SOUTH ARCOT LIGNITE

Temperature of carbonization	
i. Combustion zone temp., °C.	670
ii. Gas cross over temp., °C.	450
iii. Vapour off take temp., °C.	150
Sp. gr. at 30°C.	0·962
Distillation of tar (w.f.)	
Temp. at which distillation begins, °C.	98
Fraction	
up to 160°C., %	3·5
160°—220°C., %	12·8
220°—270°C., %	25·4
270°—300°C., %	14·4
300°—360°C., %	15·1
Pitch	26·4
Loss	2·4
Viscosity at 50°C.	1·92°E.
Softening point of pitch, °C.	46
Ash in tar, %	0·42
Phenols, %	21·40
Pyridine bases, %	0·72
Paraffin content, %	11·80

The difficulties were overcome by making the following changes: (1) The charging buckets were insulated and hot inert gases at about 160°-180°C. were introduced into them; (2) A 2-in. line was taken from the return production gas and introduced below the valve of the lower charging hopper into the retort.

These changes resulted in (*i*) The raw briquettes, instead of first coming in contact with the maximum temperature zone, were gradually heated in the charging hoppers. This, in fact, acted as a pre-drying zone and a part of the moisture was given out; (*ii*) The temperature in the upper part of retort could be controlled by regulating the quantity of the recycle of production gas.

Thus, there is a gradual temperature rise as the briquettes travel down the retort. By regulating the offtake temperature, cracking of tar was prevented and practically the whole of tar was recovered in the condensation unit.

The calorific value of the gas was considerably increased by recycling a part of the gas. The effect of these modifications on the yield of products is given in Table 3. A typical analysis of the tar is given in Table 4.

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DISCUSSION

Dr M. S. Iyengar: Why were pilot plant tests on drying of lignite undertaken ? What were the changes made in the carbonizer ?

Dr C. V. S. Ratnam: Conventional drying system is costlier than flash drying. Lignite, due to its very nature, does not withstand conventional drying. It is also important to maintain 9 per cent moisture in the dried lignite. Pilot plant tests were undertaken to study these aspects. The main alteration introduced in the carbonizer was the incorporation of the spuelgas system.

Binderless Briquetting and Carbonization of Wardha Valley Coal

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The influence of different variables on binderless briquetting and carbonization of Ghughus coal were studied. Releasing locked air pockets by 'breathing' gave stronger green briquettes. Higher pressures and temperature increased the crushing strength of green briquettes. However, in some instances, pressures higher than 16 tons/sq. in. did not improve the strength of briquettes. Best results were obtained by briquetting coal passing through 72 mesh at 200°C. and 16 tons/sq. in. Moisture is necessary for self-binding of briquettes. High temperature carbonization of briquettes prepared at 100°-200°C. and 16-24 tons/sq. in. gave a hard coke of high crushing strength. Washed coal fractions (1·5 sp. gr.) dried at 40°C. gave better results than those dried at 110°C. Water-resistance and crushing strength of washed fractions were higher than those of raw coal. Slow rate of heating prevents formation of cracks on the surface of char.

Preliminary studies of the properties of Wardha Valley coals from Ballarpur, Sasti, Hindustan Lalpeth, Majri and Ghughus collieries have shown them to be low rank non-caking coals characterized by high moisture high ash and high volatile matter contents and low washability. Examination of vitrain-rich fractions of the coals yielded weakly caking residues on carbonization. Considerable proportion of non-caking constituents like fusain and mineral matter were observed[1].

Utilization of such coals for metallurgical purposes is possible by briquetting and carbonization. Briquetting of coal powder with a binder

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yields a fairly stable green briquette and it is equally possible to obtain good results without using a binder. This paper describes the results obtained by binderless briquetting of Ghughus coal followed by carbonization.

Iyengar and coworkers[2-6] investigated extensively binderless briquetting of several Indian coals and lignites and indicated a relationship between the rank of coals and the behaviour on briquetting. They concluded that the strength of the briquette is partly due to the forces of cohesion and partly due to the forces of adhesion. Low rank lignites and coals were found to form self-bonded briquettes of considerable green strength.

In Australia, Donnelli and coworkers[7] investigated the production of coked briquettes from West Australian sub-bituminous coals. Kennedy and coworkers[8] investigated the production of metallurgical fuel from Victorian Brown coals and reported a 'char' with a crushing strength of 2550 lb./sq. in., 80 per cent shatter index on 1·5 in. and an apparent density of 1·16 g./cc.

BINDERLESS BRIQUETTING OF WARDHA VALLEY COAL

Low rank Wardha Valley coals appeared promising in giving satisfactory briquettes without a binder. Ghughus coal being a typical Wardha Valley coal was chosen for the investigation and the following variable factors were studied:

1. Coal (*a*) Raw unwashed coal
    (*b*) Washed fractions of coal
    (*c*) Different sizes of coal particles
    (*d*) Coal with or without moisture
    (*e*) Precarbonized coal

2. Briquetting (*a*) Briquetting pressure: 8, 16 and 24 tons/sq.in.
    (*b*) Temperature: 25°, 100°, 150°, 200°, 250°C.
    (*c*) No breathing, breathing once, and breathing twice

3. Carbonization (*a*) Maximum temperature
    (*b*) Rates of heating

Properties Evaluated. The briquettes and chars therefrom cannot be evaluated on the same basis as coke, particularly with reference to shatter and abrasion tests[7]. The test universally applied to the briquettes is the crushing strength test. The 24-hour water immersion test has a special significance in testing of briquettes and chars and was therefore done.

Qualitative observations on shrinkage, surface conditions, cracks and fissures, and surface hardness were also recorded to qualitatively convey the nature of products.

PROCEDURE

The coal sample was crushed to —7, —36, —72 and —120 mesh sizes. Where influence of washing was to be determined, gravity separation in zinc chloride solution of required specific gravity was performed; the floats were thoroughly washed in water, free of chloride and dried either at 110° or at 40°C.

'Breathing', as practised in plastics industry, was tried on coal with beneficial results. The procedure consists in pressing the charge once (not necessarily to the designed pressure), releasing the pressure for a short time, then pressing again to the predetermined pressure. Breathing allows the locked air to escape from the coal mass. The compressed air pockets tend to expand on release of pressure or more damagingly during earlier stages of carbonization. As can be seen from the experimental data (Table 1), breathing twice gave better results.

Bulk of the tests were done in a 5/8 in. diam. die, since this size was suitable for the hydraulic press available in the laboratory and the standard Gray-King assay apparatus. A few tests were also done with a 1 in. diam. die to confirm the low pressure results. The press used was a hot-platten, controlled temperature hydraulic press. The pressing was done at 16,100 lb./sq.in., 32,200 lb./sq.in. and 48,300 lb./sq.in. and the briquetting was done at room temperature and at 100°, 150°, 200° and 250°C.

Carbonization was done in a standard Gray-King type apparatus. For carbonization of larger briquettes, other electrically heated retort furnaces were used.

Compression strength was tested in an electrically operated universal testing machine. Data recorded in the tables are averages of five tests. The green briquettes obtained under various conditions were carbonized in a Gray-King assay unit at 600° and 1000°C. Ten briquettes were carbonized for each test. Ordinarily, a rate of heating of 5°C./min. was used but was reduced to 2°C./min. to overcome cracks in later experiments. The chars obtained were subjected to crushing and water stability tests. The results are presented in Tables 5 to 9.

RESULTS AND DISCUSSION

Results obtained with the different variables are presented in Tables 1-4.

TABLE 1—EFFECT OF BREATHING ON CRUSHING STRENGTH OF BRIQUETTES

Briquetting pressure, lb./sq. in.	Crushing strength, lb./sq. in.					
	No breathing		One breathing		Two breathings	
	R.T.	100°C.	R.T.	100°C.	R.T.	100°C.
16,100	322	2012	483	2415	885	3059
32,200	725	3120	1191	3461	1932	3622
48,300	..	3139	..	3300	1771	3381

TABLE 2—EFFECT OF TEMPERATURE AND PRESSURE ON GREEN STRENGTH

(−72 mesh size, two breathings)

Briquetting pressure, lb./sq. in.	Crushing strength, lb./sq. in.				
	R.T.	100°C.	150°C.	200°C.	250°C.
16,100	885	3059	..	..	..
32,200	1932	3622	3783	3780	3780
48,300	1771	3381	4669	5313	5375

TABLE 3—EFFECT OF PARTICLE SIZE ON CRUSHING STRENGTH

(two breathings)

Mesh B.S.S.	Briquetting pressure, lb./sq. in.		
	16,100	32,200	48,300
	At room temperature (25°C.)		
−7	(not possible to make adherent briquette at room temperature)		
−36	483	1775	2254
−72	885	1932	1771
−120	1127	2978	3703
	At 100°C.		
−7	1288	2013	2254
−36	2254	3445	3285
−72	3059	3622	3381
−120	3301	4347	4669

TABLE 4—BRIQUETTING OF WASHED—1·5 Sp. Gr. FRACTION (−72 mesh, two breathings), DRIED AT 40°C.

(Moisture, 7·3%; ash, 11·2%; volatile matter, 30·6% and fixed carbon, 50·9%)

Briquetting pressure, lb./sq. in.	Crushing strength, lb./sq. in.	
	Briquetted at room temp.	Briquetted at 100°C.
16,100	885	1851
32,200	1771	3810
48,300	2576	4025

TABLE 5—CRUSHING STRENGTH OF CHARS

(—72 mesh size and two breathings)

Briquetting pressure, lb./sq. in.	Crushing strength, lb./sq. in.					
	Briquetted at room temp.			Briquetted at 100°C.		
	Green briquette	Char (L.T.C.)	Char (H.T.C.)	Green briquette	Char (L.T.C.)	Char (H.T.C.)
16,100	885	125	150	3059	750	1250
32,200	1932	500	750	3522	2250	3250
48,300	1771	875	1125	3381	2150	3125

TABLE 6—CRUSHING STRENGTH OF THE CHAR OBTAINED BY HIGH TEMPERATURE CARBONIZATION

Briquetting pressure, lb./sq. in.	Crushing strength, lb./sq. in.									
	Briquetted at									
	Room temp.		100°C.		150°C.		200°C.		250°C.	
	Briquette	Char	Briquette	Char	Briquette	Char	Briquette	Char	Briquette	Char
16,100	885	150	3059	1250	..	..	..	..	..	..
32,200	1932	750	3922	3250	3783	3125	3780	3000	3780	3000
48,300	1771	1125	3181	3125	4669	..	5313	4250	5375	..

TABLE 7—CRUSHING STRENGTH OF CHAR OBTAINED FROM WASHED FRACTION

(sp. gr. 1·5)

Briquetting pressure, lb./sq. in.	Crushing strength, lb./sq. in.			
	Briquetted at room temp.		Briquetted at 100°C.	
	Green briquette	Char	Green briquette	Char
16,100	885	125	1851	1625
32,200	1771	1250	3810	3750
48,300	2576	2375	4025	..

TABLE 8—IMMERSION TEST ON H.T.C. CHARS

(Particles, —72 mesh; Briquetting temp., —100°C.; two breathings)

Briquetting pressure, lb./sq. in.	Crushing strength, lb./sq. in.			
	Char from raw coal		Char from washed fraction	
	before immersion	after immersion	before immersion	after immersion
16,100	1250	1000	1625	1475
32,200	3250	2500	3750	3050
48,300	3125	2800	..	5625

TABLE 9—GENERAL ANALYSIS OF H.T.C. CHAR

(a) Proximate analysis, (%) (for char from washed coal)

Ash	18·3
Volatile matter	3·6
Fixed carbon	78·1

(b) Gray-King H.T.C. assay

Yield per 100 g. of dry coal	Raw coal	Washed coal (sp. gr. 1·5)
Char, g.	72·35	68·39
Tar and liquor, g.	17·83	20·36
Ammonia, g.	0·073	0·084
Gas at NTP, l.	16·6	28·73

Table 1 shows that breathing improves the crushing strength at all pressures and temperatures and the effect is more pronounced at lower pressure. Increase in temperature (Table 2) rapidly increases the crushing strength initially, but maximum is reached for a given pressure. All briquettes prepared at room temperature had a dull surface and poor abrasion resistance. Higher temperatures of briquetting improved the crushing strength and also the nature of the surface which became shiny, hard and abrasion-resistant, but these were true only for the surface layers. The wear resistance is markedly decreased once the hard surface is removed. Table 3 shows that decrease in particle size increases the crushing strength. Washed fractions of coal (Table 4) gave increasing strength to briquettes with increasing pressures and temperatures, which is quite the opposite in the case of raw coal briquettes. Under similar conditions the washed fractions gave stronger briquette than raw coal. Washed coal when dried at 110°C. gave a poor briquette, but when dried at 40°C. for 3 hr (moisture, 4·3 per cent) it gave a self-binding satisfactory briquette. With charge containing more than 8 per cent moisture, water trickled from the mould, when pressed at 32,200 and 48,300 lb./sq. in. All the green briquettes disintegrated within a few minutes of water immersion. It was found that storage reduced the crushing strength and therefore the tests were performed on the day briquettes were made.

To overcome the difficulty of heavy shrinkage and cracks during carbonization, preheating the charge at 300°C. for one hour was tried. The results were not found to be encouraging.

It is seen from the tables that h.t. chars are consistently stronger than corresponding l.t. chars. In general, increase in pressure and temperature used in briquetting resulted in stronger chars. However, at a briquetting pressure of 32,200 lb./sq.in. the strongest char is obtained from a briquette prepared at 100°C. Chars with more than 4,000 lb./sq. in. crushing strength are obtained by using 48,300 lb./sq. in. and about 200°C. Washed coal gave a stronger char than raw coal; the former also showed better water-resistance. Cracks already present in the briquette widen on carbonization. Cracks due to faulty briquetting are generally parallel to the basal plane. Radial fissures develop with rapid rate of heating. Cracks were absent in all briquettes and their chars prepared at 32,200 lb./sq. in. and 150°C. and above.

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DISCUSSION

Dr P. Sen: What rate of heating was maintained in the experiments ? Have any tests been done on the washed coal ?

Dr V. A. Altekar: The rate of heating in all carbonization tests at 600°C. and 1000°C. was the same (3°C./min.). But in some tests this was reduced to 2°C./min. Excessive heating rates led to breakages in briquettes. Washed fractions consistently gave higher briquette strength.

Curing, Maturing and Carbonization of Briquettes from Non-caking Coal Slack

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Briquettes from non-caking coal slacks using a lime-tar binder generally take about two weeks to attain maximum compression strength. Methods to accelerate the increase in strength in less than 24 hr and processes to obtain strong briquette coke are reported.

The upgrading of non-caking coal slack to produce a shaped smokeless domestic fuel is a two-stage process involving (1) physical upgrading of the raw coal by briquetting with or without a binder at suitable pressures and (2) low temperature carbonization of these briquettes to produce a strong, shaped semicoke.

Non-caking slack coal from Andhra Pradesh cannot be briquetted without a binder by mere application of pressure because of the high ash content and the carbon content of 80-82 per cent[1]. Attempts by the author to briquette these slacks without a binder at 15 tons sq.in. pressure using −72 mesh B.S. product were also unsuccessful. Gregory[2] stated that all types of coals can be briquetted using the "shape technique". It is, however, not clear whether coals having high ash and 80-82 per cent carbon contents can be briquetted by this technique without a binder.

A critical review on briquetting has been reported earlier[3,4]. Though pitch is a commonly used binder, the use of lime-tar mixture as binder in briquetting has been recommended[5,6] and the reaction between lime and tar and the properties of the resulting product have been studied[7,8]. Lime and tar react only in presence of moisture resulting in a pitch-like product having a higher coking value and low temperature susceptibility than original tar. Agrawal and coworkers[6,9,10] made a detailed study of briquetting

Hyderabad coals using lime-tar mixture as binder. It was reported that briquettes attained maximum crushing strength on storage for about 3 weeks. Such long storage is impractical and uneconomical from an industrial standpoint. Experiments were therefore undertaken to evolve a suitable method to reduce the storage period, taking advantage of the mechanism of lime-tar reaction, especially in presence of water vapour[5].

It was also found that the raw briquettes, although mechanically strong could not retain their shape during combustion on open grates, particularly when the fuel bed was poked. It was, therefore, necessary to develop a method to render the briquettes resistant to thermal shock.

Carbonization of briquettes without any pretreatment at 600°C. results in very poor quality char. Broadbent and coworkers[11] reported heating of briquettes at about 200°C. for a few hours in an oxidizing atmosphere followed by carbonization to produce a good quality char. Blum[12] reported similar results on oxidative thermal pretreatment of briquettes from powdered coke. These studies involve two carbonization steps—first to carbonize the raw coal and then the briquettes. The present paper discusses the results of pretreatment and carbonization of the briquettes produced from Kothagudem coals using lime-tar binder.

MATERIALS AND METHODS

One hundred parts of Kothagudem coal (KCS-N), 13 parts of low temperature tar (LST-H) and 1·3 parts of slaked lime (all on dry basis) were used to prepare the briquettes. The particle size of coal, method of preparation of binder, moisture content, temperature of mixing and method of preparation of briquettes were the same as described earlier[4,9,10], except that the briquettes were prepared in a ½ ton/hr capacity ovoid briquetting plant. The briquetting pressure in the rolls of this plant is about 1½ to 2 tons/sq.in. at the "nip". Mixing of coal and binder was carried out in a 100 lb. capacity steam jacketed "Petzholdt" turbo mixer. Uniform mixing of different raw materials could be obtained in less than 5 min. The ovoid briquettes weighed about 45 g. each and were 1·25 in. long in the longitudinal section.

EXPERIMENTAL PROCEDURE

Curing. The method of obtaining a rapid increase in the strength of the raw briquette is known as "curing". Two series of experiments were done with fresh briquettes at 80°C., one in air-oven and the other in water vapour. Fifty fresh briquettes were kept immediately after briquetting in an air-oven at 80°C. Every hour two briquettes were removed, cooled and tested for their compression strength. Similarly, about 50 fresh briquettes were stacked in unilayer on a vertical stand having several perforated shelves. The stand was placed in a closed vessel containing water at 80°C. taking care to avoid water drops condensing over briquettes. Briquettes were removed and tested as above.

Maturing and Carbonization. The maturing step consists of subjecting the briquettes to mild oxidative thermal treatment. The important variables affecting maturing of briquettes are (i) temperature, (ii) duration, and (iii) air rate. Several sets of experiments were carried out to study these variables using temperatures of 150°, 200° and 300°C. with durations of 1 and 4 hr and air rates of 0·5 and 6 cu. ft/lb./hr.

One lb. of briquettes (dry basis) was placed in unilayer on a wire mesh stand and matured at required temperature in a 2 kg. capacity Fischer and Schraeder externally heated carbonizer (Fig. 1) maintaining a rate of heating of 2°C./min. Air circulation through a distributor, placed below the briquettes was commenced at 100°C. and continued till the end of the desired maturing period. At the end of the period air was shut off and without cooling the furnace, temperature raised to 600°C. and briquettes carbonized for 1 hr at this temperature. Products of carbonization were collected and the quantities of the liquid condensates recorded. The briquettes were allowed to cool to room temperature, taken out, weighed, their physical appearance noted and point compression strength of representative pieces determined.

RESULTS AND DISCUSSION

Fig. 2 represents the ovoid briquette compression strength on storage at room temperature. The trend of increase of strength is similar to that reported previously[10] and takes about 3 weeks to attain a maximum strength of about 380 lb./sq. in. This increase in strength is peculiar to lime-tar binder unlike briquettes made using pitch or asphalt as binder and may be attributed to lime-tar reaction itself. It may also be partially due to the nature of low temperature tar which on storage in air and light is reported to polymerize giving a product of higher pitch content[13]. Clark and Hodsman[5] reported maximum increase in viscosity in lime-tar mixture kept at 70°C. with continuous stirring after 7 hr. According to Iyengar[6] the product sets to a cheesy solid after ten days. The longer period for attaining maximum strength as observed in the present studies may be mostly due to lower storage temperatures and presence of about 90 per cent of another heterogenous phase of coal in the mass of the briquettes.

Curing. Representative data from several tests obtained by curing the fresh raw briquettes in (a) air-oven, and (b) in water vapour at 80°C. are presented in Fig. 3. In both cases the briquettes increase in strength initially and attain a constant value after a slight drop. The maximum strength attained in case (a) was 220 lb. after 7 hr and in case (b) 245 lb.

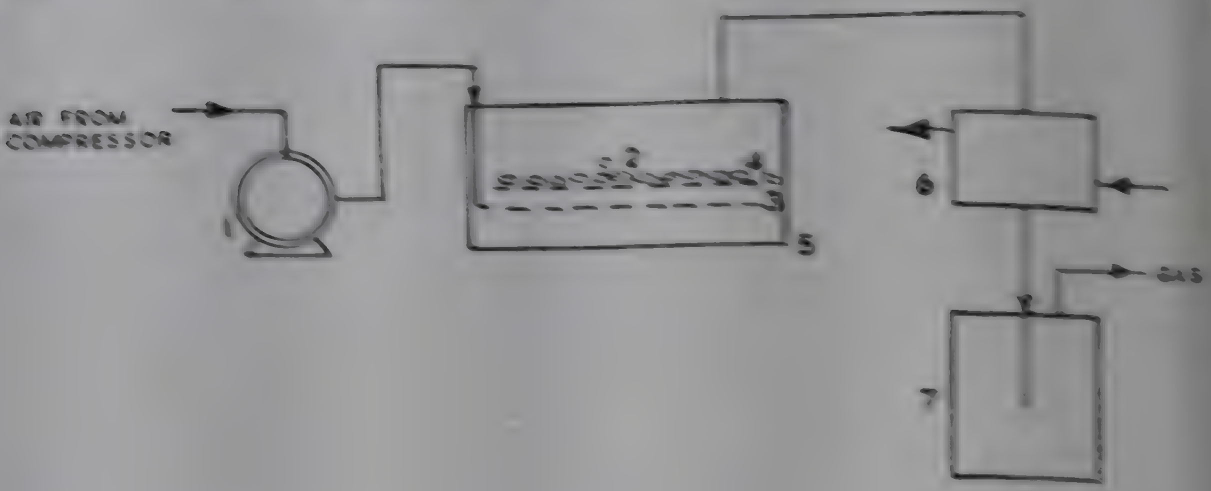

FIG. 1—FLOW SHEET OF MATURING AND CARBONIZATION PROCESS (1) Wet-gas meter (2) Ovoid briquettes (3) Air-distributor (4) Perforated tray (5) Carbonizer (6) Cooling system (7) Tar oil and aqueous liquor

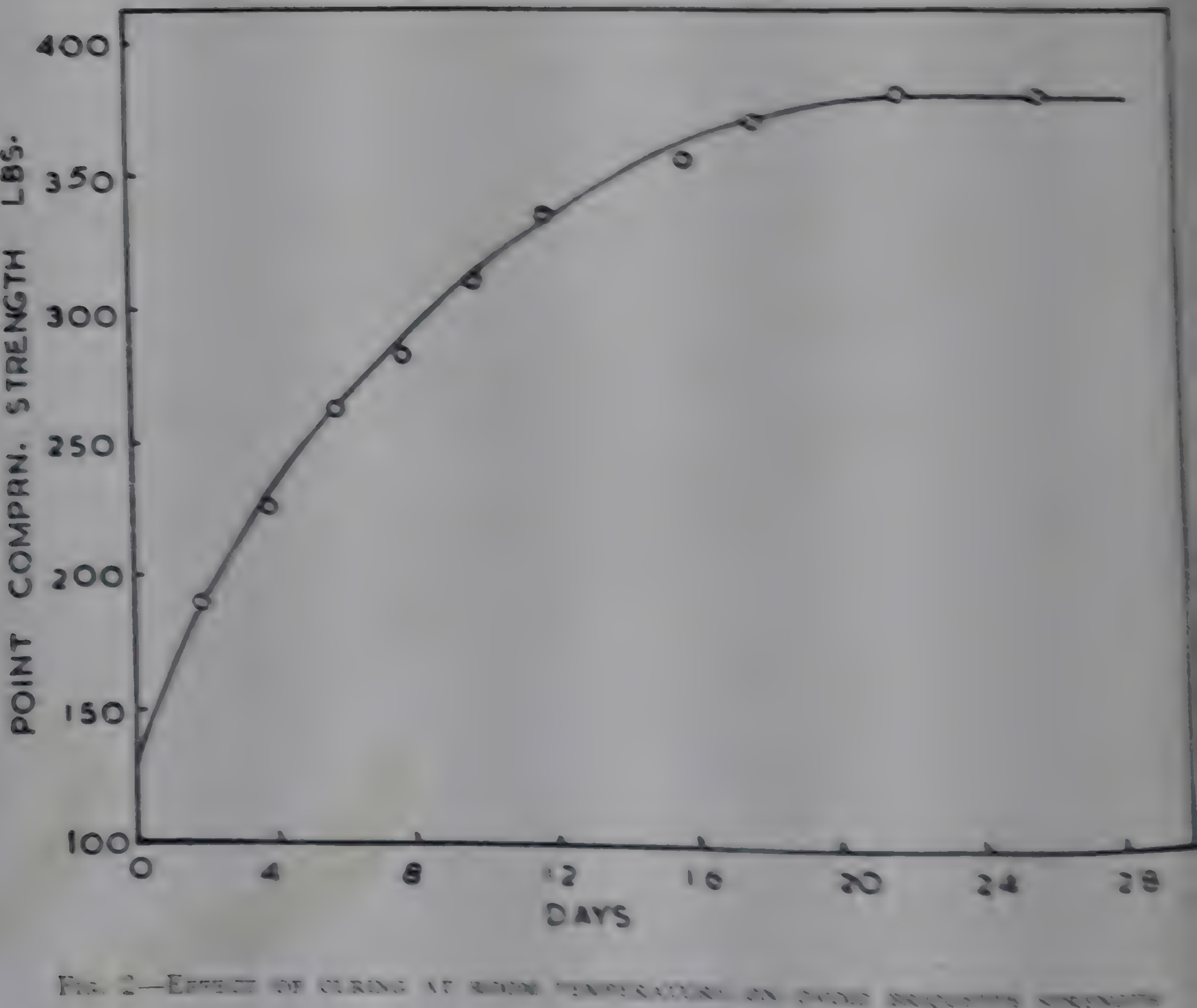

FIG. 2—EFFECT OF CURING AT ROOM TEMPERATURE ON OVOID BRIQUETTE STRENGTH

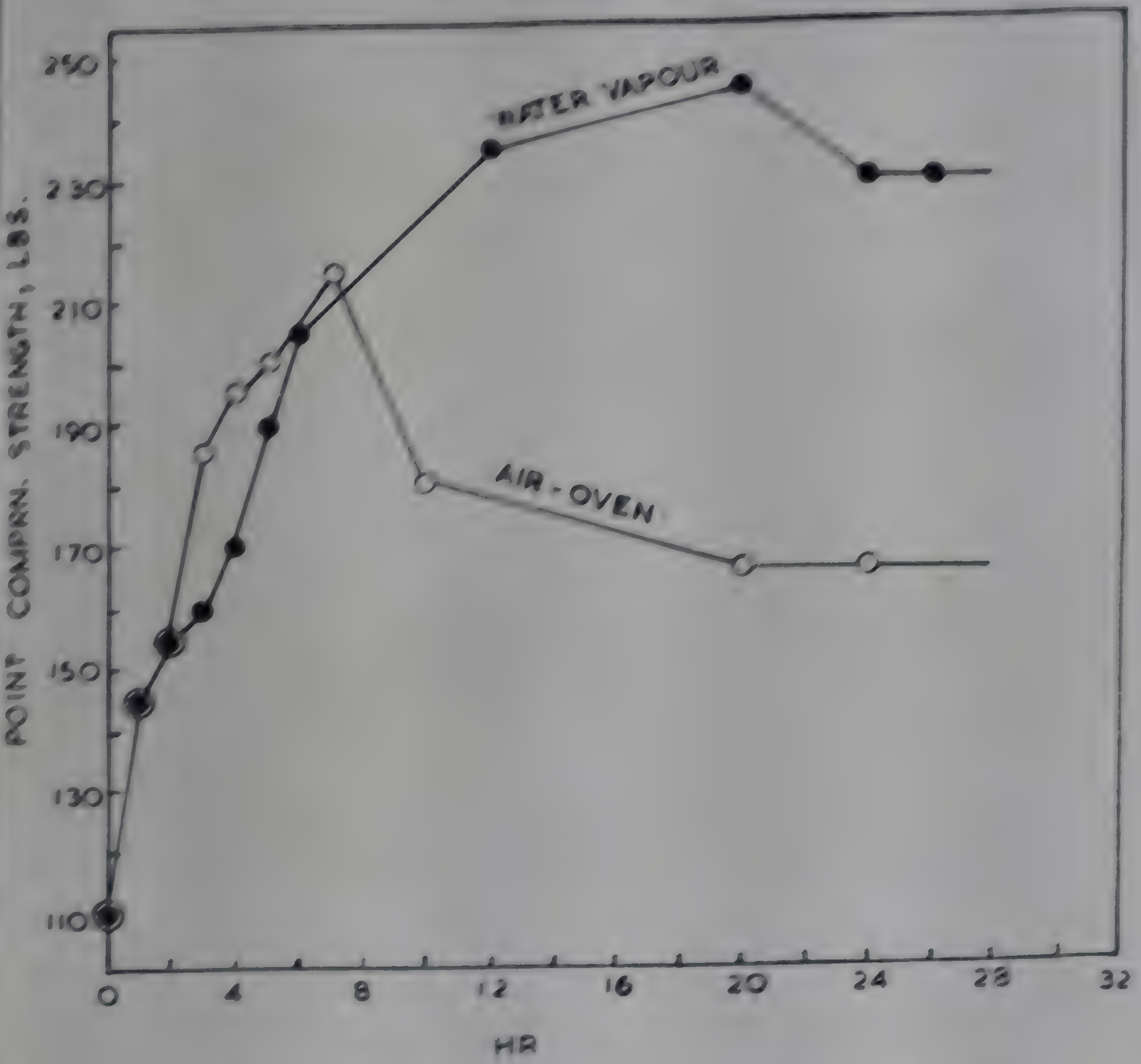

FIG. 3—EFFECT OF CURING ON OVOID BRIQUETTE STRENGTH

after 20 hr starting from initial raw briquette strength of 110 lb. in both cases. The drop in strength was more marked in (a).

Briquettes stored in air at room temperature attained maximum strength of 380 lb. after about 3 weeks and maintained thereafter (Fig. 2).

As discussed earlier, the factors responsible for promotion of lime-tar reaction and increase of compression strength are moisture, temperature and also, probably, air. In case (a) though the last two conditions were fulfilled, quick evaporation of moisture probably resulted in a limited increase in strength. In case (b) though moisture and temperature conditions were maintained air was practically excluded. These might have adversely affected the increase in strength, showing the presence of air as well as moisture at slightly elevated temperature as essential to attain higher briquette strength.

Maturing and Carbonization. Published literature[11,12,14] on pre-treatment before carbonization to improve the char quality or to reduce

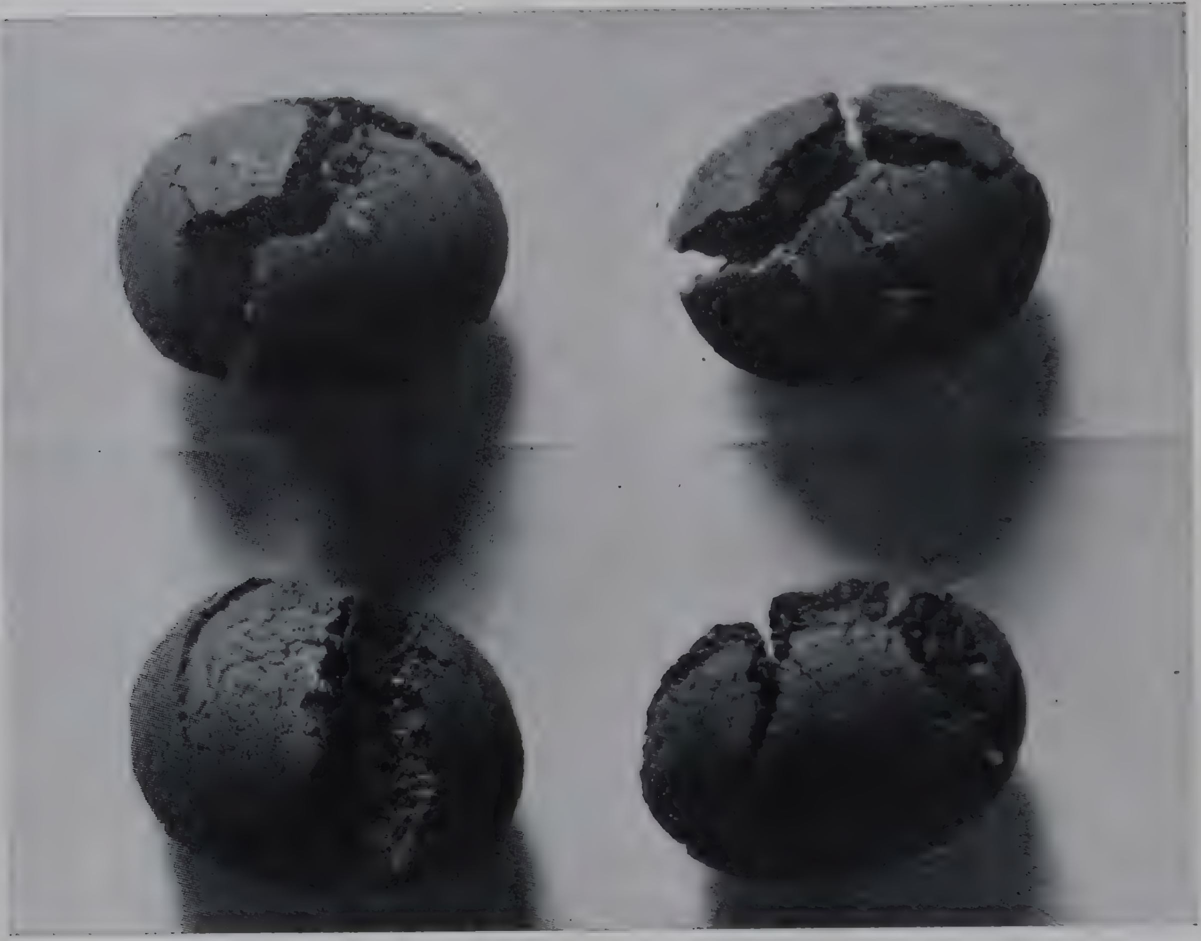

FIG. 4—CARBONIZED BRIQUETTES: Matured at 300°C. for 4 hr at 6 cu.ft lb./hr air rate

the smoke emission from the product on combustion mainly consists of blowing gas containing free oxygen at temperatures below the distillation point of any of the constituents.

Table 1 gives the results of carbonizing the ovoid briquettes with and without maturing under different conditions. It can be seen that when the briquettes are carbonized without maturing, the char has only 15 lb. compression strength, or 5 per cent of the raw briquette strength. Maturing for 1 hr at all the three temperatures using 0·5 cu. ft air rate (Experiments No. 3, 7 and 11 in Table 1) has resulted in poor strength of char. However, 4-hr duration has shown better results. Maturing at 300°C. has failed in all cases. This probably caused excessive oxidation or increased rate of gas evolution resulting in an incoherent product. Fig. 4 shows the physical appearance of char from Experiment No. 8 caused by severe conditions of maturing. The surface of this product was hard to scratch and gray in appearance. Product from Experiment No. 6 also had a fissured structure.

A maturing temperature of 150°C. gave poor results except for 4-hr duration, at 6 cu. ft air rate. At this air rate and/or 200°C. maturing temperature, the results were generally better. The strongest char was obtained by maturing at 200°C. at 6 cu. ft air rate for 4 hr, resulting in almost 100

TABLE 1—RESULTS OF MATURING & CARBONIZATION OF OVOID BRIQUETTES

(Temp. of carbonization, 600°C.)

EXPT No.	MATURING CONDITIONS			POINT COMPRESSION STRENGTH OF CHAR lb.	YIELD OF CHAR %	TAR OIL %	AQUEOUS LIQUOR %
	Temp. °C.	Duration hr	Air rate cu. ft/hr				
1.	..	..	..	15	70·9	10·7	8·9
2.	150	1	6·0	100	69·0	11·1	10·6
3.	150	1	0·5	27	71·4	11·39	7·3
4.	150	4	6·0	300	66·4	7·9	10·2
5.	150	4	0·5	125	69·4	8·9	8·9
6.	300	1	6·0	120	70·4	3·4	16·6
7.	300	1	0·5	20	69·6	8·2	11·1
8.	300	4	6·0	Negligible	wt not taken	1·5	23·6
9.	300	4	0·5	35	70·4	6·5	12·5
10.	200	1	6·0	300	70·3	7·7	12·3
11.	200	1	0·5	45	69·5	11·3	6·9
12.	200	4	6·0	360	76·1	3·8	17·5
13.	200	4	0·5	130	69·9	7·6	9·1

per cent recovery of raw briquette strength. Char was also free of fissures or cracks; volumetric shrinkage was one-third of volume of raw briquettes.

Table 1 presents data on the yield of char and liquid byproducts. Increasing the maturing temperature or duration or air rate resulted in lower yield of tar oil and higher yields of char and aqueous liquor. Some discrepancies have been observed in char yields from maturing tests at 150°C. and these may be due to experimental errors.

Curing of fresh briquettes in air at 80°C. resulted in increase of compression strength from 110 to 220 lb. after 7 hr, while in water vapour the increase was about 250 lb. after 20 hr. Strong shaped char was obtained by maturing at 200°C. for 4 hr at 6 cu. ft/lb./hr air rate followed by carbonization at 600°C. Increase in duration of maturing or air rate resulted in increased char strength, except at 300°C. Increase in temperature, duration and air rate in maturing resulted in increased char and aqueous liquor yields and decreased tar oil yield.

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Studies on Utilization of Kashmir Lignite

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Kashmir lignite with an ash content of about 40 per cent could be briquetted at pressures ranging 2-15 tons per sq. in. without binder, the briquettes made at higher pressures being stronger. Lime-treatment of lignite prior to briquetting did not improve the crushing strength or water resistance. Blending of lignite with anthracite improved the water resistance of the briquettes. The poor combustion of raw or briquetted lignite was found to be due to the low fusion point of ash. The combustibility of lignite briquettes could be improved by blending with sawdust or charcoal (10-20 per cent).

The fuel used for domestic and industrial purposes in the State of Jammu and Kashmir in India is based primarily on firewood from the forests in the State, and to a certain extent coal brought from Bihar. The State is believed to lose an annual revenue of over a million rupees by burning wood of high market value. The extensive deforestation over the past several years has created serious problems in soil conservation and agriculture. An important problem facing the State is the supply of a suitable fuel to the public and to industry to replace firewood.

The occurrence of lignite and anthracite in Jammu and Kashmir was reported as early as 1920. Middlemiss[1] estimated the total reserves of lignite at 128 million tons in Nichahoma and Shaliganga areas. Recent surveys indicate that an area 50 miles long and 10 miles wide in this region contains about 86 million tons of lignite at a depth of 150 ft. Early tests by the Geological Survey of India revealed that the lignite had a high ash content (about 40 per cent); it did not, therefore, find acceptance as a domestic fuel by the public. Only limited quantities were used as fuel in small boilers.

The Regional Research Laboratory, Hyderabad, at the request of the Jammu and Kashmir Government, undertook a study on the utilization of Kashmir lignite with special emphasis on its use as a domestic and industrial fuel. Some of the results of these studies are presented here.

EXPERIMENTAL

Representative samples (about 500 lb.) of lignite from the Nichahoma area and anthracite from the Kalakot area were used. Sampling and proximate analysis were conducted according to the standard procedures[2].

Briquetting. The materials were powdered to −72 mesh B.S.S.; a hydraulic press was used for higher briquetting pressures and an ovoid briquetting plant of 0·5 ton/hr capacity for lower pressures. To prepare briquettes from blends of lignite with anthracite, sawdust, charcoal and non-caking Kothagudem coal, the materials were each powdered separately to −72 mesh B.S.S. and thoroughly mixed in the required proportions before briquetting. In all cases, the moisture content of the powder was maintained at about 12 per cent.

In some tests, briquettes were prepared from lignite powder after addition of aqueous sodium hydroxide solution or slaked lime. In the latter case sufficient water was added to make the mixture into a paste. The mixtures were then digested for 0·5 to 1 hr at 80°-90°C. The moisture content of the mixtures at the time of briquetting was about 28-30 per cent when ovoid briquettes were prepared at a pressure of 1·5-2·0 tons/sq. in., and 12-16 per cent when briquetted at 10 tons/sq. in.

Combustion Tests. Tests on combustion of raw and briquetted lignite (with and without blending components) were conducted in a test oven of 5 in. i.d. and 3 in. height. The oven was lagged inside so that the fuel chamber had an inner diameter of 2·5 in. A chimney 6 in. high, was kept on the fuel bed. A thermocouple was kept at the centre of the fuel bed and a thermometer on the top of the chimney. In each test about 80 g. (dry basis) of briquette pieces (0·5 in. × 0·25 in. size) were evenly distributed upon a layer of about 6 g. of wood chips placed on the grate. A lighter was used for exactly 2 min. to ignite the fuel bed. Temperatures of the bed and flue gases were noted at regular intervals. When the fuel bed temperature dropped to about 30°C. after combustion, the residue was ground to −72 mesh and its average content of combustible matter was estimated. For some tests on combustion of ovoid briquettes, a bigger oven, 6 in. diam. and 4 in. height was used.

RESULTS AND DISCUSSION

General Properties. The lignite wet to touch, had a dirty brown colour and ranged in size upto 8 in. The anthracite lumps had a dark glossy surface. Proximate analyses of lignite and anthracite are given in Table 1. Raw lignite, as received from the mine, was found to contain 39 per cent moisture. The sample after air-drying for 2 days contained 24·4 per cent moisture and 37·8 per cent ash. On the other hand, the anthracite sample had lower moisture, ash and volatile matter contents. The low temperature Gray-King assay at 600°C. on lignite showed (Table 2) that the tar yield was quite low and liquor yield high. The Gray-King char contained 65·7 per cent ash. It is apparent that such a char cannot be ignited or burnt satisfactorily in ordinary domestic ovens. The initial deformation (softening) point of lignite ash determined in the Leitz Heating Microscope was only 1200°C. (Table 3), whereas that of anthracite was 1450°C.

Briquetting of Lignite. Although raw lignite is mined in slabs (about 1 ft × 1 ft × 8 in. thick), it disintegrates into slate-like pieces on storage due to loss of moisture. Briquetting of the slacks thus produced is therefore desirable to conserve the material. Tests were therefore undertaken to study the briquettability of the lignite (Table 4). Lignite briquettes prepared at 10 and 15 tons/sq. in. pressures in a hydraulic press showed high initial crushing strengths which further increased by about 10 per cent after 4 days storage in air and 20-30 per cent after 20 days. The shrinkage in size of briquettes after storage was about 30 per cent which might be partly responsible for the rise in strength[3].

The well-known[4,5] use of alkali-treated lignite as binder in briquetting was tried in the case of Kashmir lignite. Briquettes were prepared by thorough admixture with a solution of sodium hydroxide or a suspension of slaked lime as described in the experimental procedure. As a blank test, briquettes were prepared after addition of water alone to form a paste followed by digestion at 80°-90°C. It was found that alkali-treated lignite briquettes had lower crushing strengths than the untreated lignite briquettes (items 1, 2, 3, Table 4). This is in accordance with the observations of earlier workers[6,7]. Ovoid briquettes prepared from untreated lignite had an initial point compression strength of 25 lb. which increased ten-fold in about 15 days.

Briquettes were also prepared from mixtures of lignite and other fuels such as anthracite, charcoal and sawdust which are easily available in Jammu and Kashmir State. For comparison, blends of lignite and a non-caking coal from Andhra Pradesh were also briquetted. It can be seen from Table 4 (items 4-7) that the crushing strengths of blended briquettes determined one hour after preparation were generally lower than that of pure lignite briquettes. The strengths of lignite-anthracite briquettes were distinctly higher than those of others, probably due to the good briquettability of anthracite itself.

All the lignite briquettes mentioned in Table 4 showed poor water

TABLE 1—PROXIMATE ANALYSIS OF KASHMIR LIGNITE AND OTHER FUELS

(as % on air-dried basis)

	KASHMIR LIGNITE	KALAKOT ANTHRACITE	CHARCOAL	SAWDUST	NON-CAKING COAL (KOTHAGUDEM)
Moisture	24·4	0·5	6·0	5·7	8·2
Ash	37·8	16·4	5·9	2·6	19·2
Volatile matter	29·0	13·3	23·7	80·5	25·8
Fixed carbon (by difference)	8·8	69·8	64·4	11·2	46·8

TABLE 2—GRAY-KING ASSAY OF KASHMIR LIGNITE

YIELDS PER 100 g. OF DRY LIGNITE AT 600°C.		PROXIMATE ANALYSIS OF GRAY-KING ASSAY COKE AT 600°C. (AIR-DRIED BASIS, %)	
Coke, g.	69·38	Moisture	1·4
Tar, g.	5·60	Ash	65·7
Liquor, g.	13·02	Volatile matter	9·3
Gas, litres	10·28	Fixed carbon	23·6

TABLE 3—FUSION CHARACTERISTICS OF KASHMIR LIGNITE, OTHER FUELS AND THEIR BLENDS UNDER MILDLY-REDUCING ATMOSPHERE

(Hydrogen saturated with water vapour)

BASIC FUELS	KASHMIR LIGNITE (L)	KALAKOT ANTHRACITE (A)	CHARCOAL (C)	SAWDUST (S)	NON-CAKING COAL (KOTHAGUDEM) (N)
Initial deformation point, °C.	1200	1450	>1400	1290	1445
Hemispherical point, °C.	1350	>1600	>1400	>1400	1500
Flow point, °C.	1380	>1600	>1400	>1400	1510

BLENDS (DRY BASIS)	L : A (85 : 15)	L : A (69 : 31)	L : A (58 : 42)	L : A (10 : 90)	L : C (90 : 10)	L : S (90 : 10)	L : N (90 : 10)
Initial deformation point, °C.	1240	1255	1255	1350	1240	1240	1220
Hemispherical point, °C.	1365	1375	1415	>1460	1305	1340	1335
Flow point, °C.	1380	1385	1420	>1460	1320	1355	1380

esistance. Briquettes made of anthracite alone or admixed with lignite up to 40 per cent showed improved water resistance.

Combustion of Lignite. Preliminary combustion studies of air-dried Kashmir lignite in a test oven with a 1 sq. ft grate area revealed that a considerable proportion of unburnt lignite remained with the ash even under the best conditions of combustion. A small oven of 2·5 in. diam. grate was used to test the combustion of lignite under controlled conditions. Examination of the ash and partially burnt lignite pieces left on the grate revealed that invariably, the centre core of the pieces remained black under a smooth and dense outer cover of ash. Microphotographs of these ash pieces showed that the outer layer of ash was a thin and fairly hard crust indicating the start of fusion of ash. Examination of ash from combustion of pure lignite briquettes in a petrographic microscope revealed the presence of a few glass particles indicating fusion of mineral components of lignite. These phenomena are attributed to the low softening point (1200°C.) of ash from Kashmir lignite (Table 3).

It is well-known[8,9] that the temperature 1200°C. is considered critical in the formation of clinker. It appears that during the combustion of Kashmir lignite in open grates a temperature of about 1200°C. is reached for short periods on the surface of the fuel, causing fusion of the ash particles to form a dense layer which might be preventing free diffusion of air into the inner core. This coupled with the high ash content might be the reason why in actual practice Kashmir lignite was always found to show incomplete combustion in domestic appliances.

To improve the combustion characteristics of Kashmir lignite, it was blended with other fuels; the softening points of ashes from these fuels were all above the critical range (Table 3). It is further seen from the table that their initial deformation point is raised by 40°C. by the addition to lignite of 10 per cent of anthracite, charcoal or sawdust.

Briquettes prepared from the blends were burnt in the test ovens. Items 1-5 in Table 5 represent tests conducted in the small oven (2·5 in. diam. grate) and item 6, the tests in the bigger oven (6 in. diam.). In the former case broken briquette pieces (0·5 in. diam.; 0·25 in. thick) were used and in the latter, ovoid briquettes (1 in. × 1·5 in.). It is seen from Table 5 that even when only 10 per cent sawdust and charcoal were blended with lignite, the unburnt combustible matter in the residual ash dropped by 30-50 per cent. With 30 per cent of the blending component, combustion was almost complete. Anthracite, on the other hand, hindered combustion. Tests using anthracite alone showed that even after lighting with a gas flame for 0·5 hr, the fuel bed could not maintain self-supporting combustion except when the chimney height was increased, indicating the low reactivity of anthracite. Lime-treated lignite ovoid briquettes showed poorer combustion than lignite blended with other fuels.

Petrographic and other examination of ashes from combustion of

TABLE 4—CRUSHING STRENGTH OF BRIQUETTES FROM KASHMIR LIGNITE AND BLENDS

(Total crushing strength in lb./sq.in.)*

MATERIAL	BRIQUETTING PRESSURE, tons			
	10	15	2	
	(hydraulic press)		Hydraulic	Ovoid
Lignite alone				
1 hr after briquetting	2540	2820	850	25
Maximum on storage	3250	3380	..	250
Lignite : Slaked lime				
98 : 2	1900	..	..	125
95 : 5	..	..	..	180
90 : 10	..	..	..	180
Lignite : Sodium hydroxide				
99 : 1	1650	..	..	..
98 : 2	1450	..	..	..
Lignite : Anthracite				
90 : 10	2540	..	500	..
80 : 20	2430	..	..	..
70 : 30	2090	..	..	..
Lignite : Charcoal				
90 : 10	2010	..	300	..
80 : 20	1980	..	..	..
70 : 30	1610	..	..	..
Lignite : Sawdust				
90 : 10	2080	..	480	..
80 : 20	1890	..	..	..
70 : 30	1655	..	..	..
Lignite : Non-caking coal				
90 : 10	2320	..	450	..
80 : 20	2150	..	..	..
70 : 30	1640	..	..	..

*Crushing strength of blended briquettes was determined one hour after briquetting. In the case of ovoid briquettes, point compression strength was determined.

TABLE 5—RESULTS OF COMBUSTION TESTS ON BRIQUETTES FROM KASHMIR LIGNITE AND BLENDS

MATERIAL	FUEL BED TEMP. MAX. °C.	CHIMNEY TEMP. MAX. °C.	COMBUSTIBLE MATTER IN FUEL TESTED (DRY BASIS) g. (a)	COMBUSTIBLES BURNT (DRY BASIS) g. (b)	UNBURNT COMBUSTIBLES % (c)*
Lignite alone	725	190	40·0	34·4	14·0
Lignite : Anthracite					
90 : 10	730	215	40·7	30·6	24·9
80 : 30	810	232	43·3	31·1	28·2
70 : 30	810	230	45·9	36·8	28·4
Lignite : Charcoal					
90 : 10	760	221	41·6	38·6	7·2
80 : 20	800	240	45·4	43·9	3·3
70 : 30	820	260	48·8	48·1	1·8
Lignite : Sawdust					
90 : 10	800	264	43·7	39·6	9·5
80 : 20	800	260	45·9	44·6	2·9
70 : 30	800	320	49·6	48·5	2·0
Lignite : Non-caking coal					
90 : 10	780	194	40·6	36·6	12·4
80 : 20	780	167	44·6	44·0	5·8
70 : 30	780	220	47·6	49·0	3·7
*Lignite : Slaked lime***					
100 : 0	520	..	270·0	92·0	66·0
98 : 2	750	..	299·1	102·5	65·7
95 : 5	700	..	230·0	119·89	47·9
90 : 10	700	..	222·1	140·28	36·7

*Unburnt combustibles (c) expressed as percentage on combustible matter originally present in the fuel taken for test: $c=\frac{a-b}{a}\times 100$.

**Ovoid briquettes burnt in the bigger oven (6 in. diam. grate).

blended briquettes showed that: (*i*) in all cases, surface ash was soft to the touch and could be easily scraped off; (*ii*) formation of a dense crust of ash on the surface was absent; and (*iii*) no glass formation could be detected.

It is therefore concluded that combustion of Kashmir lignite is hindered not only by its high ash content but also to a considerable extent by the low fusion range of its ash. The combustion characteristics can be improved by blending lignite with sawdust or charcoal[10].

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DISCUSSION

Dr C. V. S. Ratnam: It is stated in Table 1, that the air dry moisture content of Kashmir lignite is 24·4 per cent. What is its natural moisture content?

Shri D. K. Rao: The moisture content of Kashmir lignite as mined is about 39 per cent.

Dr C. V. S. Ratnam: In Table 5, the unburnt combustibles from 100 per cent lignite briquettes are given as 14 per cent under item 1 and 66 per cent under item 6. How are these reconciled ?

Dr M. G. Krishna: Item 1 refers to disc-like briquettes, about 2·5 cm. diam. and about 1 cm. thick. These were broken into four pieces of roughly equal size and used for combustion tests. Item 6 refers to ovoid briquettes (about 4 cm. long, 2·5 cm. maximum width and 2·5 cm. maximum thickness) which were used without breakage for combustion. The size difference was indicated as a footnote to Table 5. As the size of the briquette increased, combustion became poorer.

Preparation of Hard Briquette Coke from Non-caking Kothagudem Coals

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Studies to improve the strength of briquettes prepared from a high ash non-caking coal and chars therefrom are reported. The method consists of maturing of briquettes at relatively low temperatures in an oxidizing atmosphere and carbonization at 600°-900°C. Blending of non-caking coal with coking coal followed by maturing and carbonization improves the strength of the coke briquette. The char from this non-caking coal was found to be a suitable base for the production of hard coke briquette. The low temperature char briquettes on maturing in an oxidizing atmosphere followed by rapid carbonization at 900°C. gave strong briquettes with a crushing strength of 1500 lb./sq.in.

The estimated workable reserves of coking coal in India are only 780 million tons[1] and at the present rate of consumption they cannot last long. Similar difficulties are being experienced all over the world and attempts are made to conserve coking coal by using inferior coals for the production of iron and steel either by changing the design of the furnace, coke ovens, etc. or by blending low-grade coals, low temperature (l.t.) char, coke breeze, anthracite, etc. with good quality coking coals so as to produce hard metallurgical coke. Many processes to use low grade coals directly for the production of iron and steel have been reported[2,3], but the design of a commercial plant is still in the initial stages. By suitably blending or using narrow brick retorts or stamping of the blends in retorts it is possible to affect a saving upto 30 to 40 per cent of good quality coking coal.

Another approach to the problem has been to upgrade the non-caking or weakly caking coals so as to give a hard coke for blast furnace use. Many processes have been reported, of which 'Carbocoal'[4], 'Webers'[4], National Coal Board[5] processes need special mention as also the studies of Broadbent and coworkers[6], Schreiber and Mewes[7], and Blum and Nistor[8]. These processes mainly consist of carbonization of briquettes prepared from medium temperature chars with or without bituminous coal and bituminous binders. The technique of maturing to improve the strength of briquette coke has been used only by a few workers[6,8].

The uneven distribution of the coal reserves in India has also been creating difficulties in meeting the fuel demands of several industries. In India the large reserves of good quality non-caking coals are more widely dispersed than those of caking coals. If the non-coking coals can be suitably processed to get hard coke, the increasing demands of such coke for different industries can be easily met for several decades. Kothagudem coal from Andhra Pradesh is one such typical non-caking metalignitious coal having a high ash content (about 21 per cent on dry basis). The present paper describes the laboratory experiments on the effects of the following variables on the strength of Kothagudem coal or char briquettes and cokes obtained thereform:

(*i*) Blending of Kothagudem non-caking coal fines and caking coal fines from Dhanbad area.

(*ii*) Maturing under different conditions before carbonization.

(*iii*) Carbonization at different rates of heating at 600 to 900°C.

Some of the data obtained in these studies were reported earlier[9].

MATERIALS

Two types of coal slacks, one from non-caking coal from Kothagudem coalfields (KCS-N) and the other from caking coal from Dhanbad area (DCC) and l.t. char were used in these studies. The method used for obtaining the char from Kothagudem coal at 650°C. in a 25 tons/day capacity spuelgas plant has been described elsewhere[10]. The analysis of these are given in Table 1.

The low temperature tar (LST-H) and slaked lime used for preparation of binder were essentially the same as described in a previous communication[11].

METHODS

For comparative studies the coking coal was crushed, screened and the material of different sizes are mixed in suitable proportions so as to get a product having similar screen analysis as KCS-N. To achieve homogeneous mixing only −60 mesh B.S.S. product of the caking coal was used for blending, keeping the overall screen analysis of the blend same as for KCS-N.

TABLE 1—ANALYSIS OF COAL SLACKS AND L. T. CHAR

	Caking coal slack from Dhanbad area	Kothagudem coal slack KCS-N	L.T. char from Kothagudem coal
Proximate analysis (% on air dry basis)			
Moisture	1·26	8·2	4·86
Ash	14·83	19·2	20·63
Volatile matter	21·81	25·8	9·55
Fixed carbon	62·10	46·8	64·96
Caking index	16·0	non-caking	..
Gray-King assay at 600°C. for 1 hr (yield/100 g. of dry coal or char)			
Coke; g.	84·60	78·96	93·8
Tar, g.	7·09	6·08	trace
Liquor, g.	1·85	4·05	3·03
Gas, litres	10·70	10·26	3·044
Screen analysis of material used for briquetting, %			
Above 10 mesh BSS	11·02	11·02	..
10-20 mesh BSS	31·50	31·50	46·33
20-40 do	29·80	29·80	33·01
40-60 do	8·18	8·18	7·79
below 60 mesh B.S.S.	19·50	19·50	12·87

The general procedures for briquetting, storage and determination of crushing strength were the same as reported previously[11]. The height of the briquettes, generally, was equal to diameter (1·5 in.).

Maturing. For each series about 20 briquettes were placed in a muffle furnace, electrically heated to 200°C. and maintained at this temperature for 2 hr in a slight oxidizing atmosphere. The furnace was then cooled and the briquettes tested for crushing strength. This method was adopted throughout the study unless otherwise mentioned.

One set of maturing experiments was done by keeping the briquettes covered in a specially prepared mild steel container, thus avoiding contact with air. In another set the briquettes after maturing in oxidizing atmosphere, were kept in mild steel crucibles without cooling and transferred to another muffle furnace maintained at 900°C. for carbonization tests.

Carbonization. The briquettes were carbonized at the desired temperature for 1 hr using three different rates of heating as mentioned below:

(*a*) *2°C./min.* The briquettes were heated in the 1-lb. Baird and Tatlock carbonizer. The unit took about 3 hr to attain the temperature of 600°C. After maintaining at this temperature for 1 hr the furnace was switched off, samples allowed to cool in the furnace itself, and later tested for crushing strength.

(*b*) *18 to 20°C./min.* The briquettes placed in a specially fabricated mild steel crucible, were introduced into a muffle furnace and then heated to the desired temperature at 18 to 20°C./min.

(*c*) *150 to 200°C./min.* The briquettes in the mild steel crucible were introduced into the muffle furnace already heated to the desired carbonization temperature. The drop in temperature on introduction of the sample was regained by proper regulation. It took about 3 min. and 5 min. for the furnace to regain 600°C. and 900°C. respectively.

In (*b*) and (*c*) after carbonization, the crucibles were removed and cooled and the samples tested for compression strength.

RESULTS AND DISCUSSION

(*i*) The increase in strength on storage of briquettes prepared from KCS-N, DCC, the blends of these two and l.t. char are presented in Table 2. The general trend of increase in strength and the period of 3-4 weeks required to attain maximum strength are on similar lines to those reported previously[11,12,13] and are typical of briquettes made with lime-tar mixture as binder.

(*ii*) Briquettes made with caking slacks were weaker than those from blends or non-caking slacks. This may be partly attributed to the softer nature of the 'brights' from caking coal as compared to hard durainous non-caking coal with a high ash content. Poor strength might also have resulted from greater crushing of the brights during briquetting resulting in an increase in the surface not covered with binder.

(*iii*) A slight increase in the maximum crushing strength of briquettes made from blends is observed with the increase in the proportion of caking fines. Finer size (−60 mesh) of the caking fines used for blending might be responsible for this behaviour. This increase in strength might continue up to an optimum percentage of caking fines in the blend. This has not been investigated in the present studies.

(*iv*) Raw briquettes from l.t. char were very poor in strength. A considerable increase in their strength was observed by increasing the binder content and the briquetting pressure. Other experiments (not reported here) showed that a minimum of 15 per cent of lime-tar binder was required to get a satisfactory strong briquette (total crushing strength over 1000 lb.).

TABLE 2—INCREASE OF COMPRESSION STRENGTH OF BRIQUETTES ON STORAGE

[Composition of briquettes (dry basis): coal, char or blend 100 parts, tar 10 parts, slaked lime 1 part, moisture 20 per cent on dry raw material, mixed at 70°C. for 30 min., briquetting pressure: 4000 lb./sq.in.]

	COKING COAL	NON-CAKING COAL KCS-N	CONTENT OF COKING COAL IN THE BLEND, %				L.T. CHAR
			5	7·5	10	12·5	
Days of storage	Crushing strength, lb.						
Immediately after briquetting	550	590	725	730	750	..	425
after 1 day	810	890	1010	955	1000	950	430
3 days	1000	1260	1225	1180	1150	1185	400
7 days	1000	1463	1675	1725	1720	1620	420
10 days	1000	1585	..	..	..	..	435
11 days	..	..	1700	1700	1800	..	..
17 days	1050	1850	1770	1750	1850	1850	510
25 days	1170	2040	1985	2050	2100	2100	600
40 days	1340	2090	2040	2080	2200	2250	460
60 days	1390	2130	2020	2080	2180	2280	480
90 days	1675	2180	2020	2080	2185	2280	..

TABLE 3—EFFECT OF MATURING BEFORE CARBONIZATION ON THE STRENGTH OF BRIQUETTES

(Composition of briquettes: same as in Table 2)

DETAILS OF BRIQUETTES	TOTAL CRUSHING STRENGTH, lb.			
	Max. crushing strength on storage	Matured at 200°C. for 2 hr		Not matured
		Not carbonized	Carbonized at 600°C. (*rate* 2°C./*min.*)	
Non-caking KCS-N	2180	680	600	100
Blends —5% coking coal	2020	940	825	280
do 7·5%	2080	940	830	355
do 10%	2200	1100	1080	400
do 12·5%	2280	1200	1175	550
L.T.C. char*	550**	625	925	240

* —20 mesh, 15% tar; briquetting pressure of 4000/sq. in.

**Initial strength before starting the experiments.

Broadbent and coworkers mentioned that chars from spuelgas carbonization are more porous and elastic and therefore yield briquettes of poor strength. A greater quantity of binder is absorbed in the pores, needing higher percentage of binder to get satisfactory briquette strength. They suggested high briquetting pressures for such chars to improve apparent density and strength.

The coarser grain size used for briquetting might have also adversely affected the briquette strength.

Effect of Maturing. Briquettes similar to those referred in Table 2 were carbonized with and without maturing and the results are reported in Table 3. Briquettes from non-caking coal when carbonized without maturing showed some blowholes on the surface and had the lowest strength. As expected, the strength improved considerably by blending with caking coal.

Generally, maturing improved the briquette coke strength and is, as described by Broadbent and coworkers, mainly due to the double action of the maturing process. Maturing helps in 'permeation and cementing of cracks and breakages developed in the individual particles during briquetting' and results in 'slow sweating of the volatile matter of the tar'.

Further, the strength of briquettes from raw coal or blends dropped by about 50 per cent when they were matured or matured and carbonized (columns b and c, Table 3). The briquettes from l.t. char had a crushing strength of 625 lb. after maturing which increased to 925 lb. after carbonization as compared to the initial crushing strength of 550 lb. The reasons for such behaviour have already been outlined by other workers[6,8]. Carbonization of briquettes normally involves evolution of gases first from binder and later from coal. This, coupled with shrinkage of coal particles, tends to weaken the bonds between binder coke and char surfaces. These defects are remedied by using a preshrunk char for briquetting followed by maturing before carbonization.

Effect of Conditions of Maturing and Carbonization. Results of studies on the strength of briquette coke from l.t. char with different conditions of maturing and carbonization are presented in Table 4. It is noted that increase in the rate of heating or temperature of carbonization results in increased briquette coke strength.

Maturing in oxidizing atmosphere followed by carbonization gives stronger briquette coke than when the oxidizing atmosphere is not used. This observation is in accordance with that of previous workers[8,14]. Maturing in oxidizing atmosphere results in oxidation-polymerization of the bituminous binder, finally improving the coke bond produced after carbonization. This effect is more pronounced in briquettes made with lime-tar mixture as binder due to (*i*) the easy polymerization of l.t. tar and the catalytic action of lime in polymerization giving higher coking value and (*ii*) harder coke formation from lime tar[15].

TABLE 4—EFFECT OF CONDITIONS OF MATURING AND RATE OF HEATING ON THE STRENGTH OF CARBONIZED BRIQUETTES FROM L. T. CHAR

(Briquette composition: L. T. Char: −20 mesh product 100 parts, LST-L 15 parts, lime 1·5 parts, water 20 parts, mixing at 70°C. for 30 minutes and briquetting pressure of 12,000/sq.in.)

	RATE OF HEATING, °C./min.	TOTAL CRUSHING STRENGTH, lb.
Series A		
Initial briquette strength	..	1000
Carbonization without maturing (600°C.)	2	600
After maturing only	..	1350
Matured and carbonized at 600°C. (*i*)	2	1550
(*ii*)	18-20	1700
(*iii*)	150-200	1850
Matured and carbonized at 900°C. (*i*)	18-20	2150
(*ii*)	150-200	2200
Series B		
Initial briquette strength	..	850
Maturing without oxidizing atm.	..	675
Maturing with oxidizing atm.	..	1000
Carbonization of B2 above at 900°C.	18-20	1000
Carbonization of B3 above at 900°C.	18-20	2000
Series C		
Initial strength	..	870
Maturing and carbonization without intermediate cooling at 900°C.	150-200	2550

Further, maturing in oxidizing atmosphere followed immediately by high temperature carbonization without intermediate cooling results in the strongest coke briquette (crushing strength about 1500 psi). It is possible to effect further improvement on the crushing strength of coke briquette by adopting optimum temperature of maturing, duration and rate of blowing air, etc.

Though Broadbent and coworkers mentioned l.t. char as a very poor base (due to high porosity and further shrinkage up to about 20 per cent on carbonization at medium or high temperatures) for manufacturing 'bricoke', the present studies showed that carbonization of Kothagudem coal at 650°C. gave sufficiently strong base for subsequent briquetting, maturing and carbonization at 900°C. This may be due to the high ash content and durainous nature of this coal.

Most of the work reported on briquetting and hard coke preparation from low-rank coal deals with low ash non-caking coals having a carbon content in the briquettable range. Kothagudem coal which is durainous and non-caking has a high ash content and a carbon content of 80-82 per cent (dmf), presenting greater difficulties in briquetting and subsequent carbonization. Successful methods as described above in the production of hard briquette coke from such a coal will help a great deal in the production of a better and stronger coke briquette from other low-ash non-caking Indian coals.

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A Typical Study in Briquette Production

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This paper presents an account of a study made in U.K. on behalf of the National Coal Board into the suitability of applying certain processes of briquetting to fine material from a process for making smokeless fuel. Two grades of material were available—one high volatile, the other well carbonized. Recommendations were made for the adoption of a process already operating in Europe with reasonable commercial success. The study also includes considerations and recommendations on heat treatment of the briquettes to produce a smokeless grade. Improvements in the production of the smokeless fuel have reduced the amount of fine material produced and the proposed plant has not been proceeded with.

In the production of a smokeless fuel at a coking plant operated by the National Coal Board large quantities of coke breeze are rejected during the grading process. The reject breeze is of two qualities. The first which comes from the oven cores is separated at the first screening and is high in volatile matter. The second arises from the size reduction of final product and is carbonized to a greater extent.

The object of the study was to establish by what method the reject breeze, which commands only a low price, could be converted into a high-grade smokeless fuel. The investigations therefore covered two general aspects—briquetting and heat treatment. In the course of the study visits were made and discussions held both with the manufacturers of briquettes and briquetting plants in U.K., Germany and France. The solution which was finally recommended was based on experience in France. Certain trials were carried out on the actual fuel on a plant in France. The terms of reference for the study covered the commercial as well as the technical fields and approximate capital costs of the recommended plant layout were established.

BRIQUETTING PROCESS

There exist in Europe a number of designs of briquetting equipment, all of which are fairly well proved on a commercial scale. The principal task here was to establish a process flow diagram and examine the mechanical equipment which could be obtained to fit into this.

An analysis of production data for the months of June, July and August in 1959 showed that approximately 780 tons per week of mixed breeze were rejected from the coking plant under investigation. This corresponded to a production of some 3,300 tons per week of the smokeless fuel which was the final product of the plant. The average proximate analysis of the breeze over these months was:

Moisture, 12·6 per cent; ash (dry basis), 5·6 per cent; and volatile matter (dry basis), 17·8 per cent.

The basic process route therefore leads through drying, grinding, addition of binder and briquetting with final screening to remove 'flash' before passing to the next stage, which in this case was heat treatment.

Operating procedure on the coking plant can affect quite considerably the characteristics of the feed available. This, in particular, affects the proportions in which the volatile content and the carbonized content occur. The figures given above represent a reasonable picture for the purpose of the study. Deliberate changes in operating procedure, e.g. operating at higher temperatures and with longer carbonization periods, can of course affect the characteristics of the breeze feed.

In establishing process route, two basic considerations were taken into account. The first was that the high percentage of coke particles in the feed indicated that heavy abrasion was to be expected and equipment was selected with this in mind. The second was that liquid pitch should be used as a binder and this decision was influenced by the availability of supplies within a reasonable distance.

Storage and Drying. The breeze was to be fed from the storage bunkers at the coking plant into a 12-ton capacity basalt-lined surge bunker at the briquetting plant. A mechanical rodding device would be fitted at the bunker throat. The wet breeze would be led away at the rate of some 10 tons/hr into the drying equipment.

Rotary, horizontal and vertical dryers and also a pneumatic dryer were considered. A vertical type dryer was selected on the basis of low capital cost, low horse power and low heat requirements. Furthermore, its vertical arrangement occupies less floor area and there is less abrasion on the body of the dryer than with the other two. A choice exists in the method of furnace firing for the dryer and a breeze-fired furnace appears to be more economical to run than a gas-fired furnace, although the initial capital expenditure is nearly three times greater. Associated with the vertical dryer is a multi-cone type dust collector. Both the dryer and the collector feed through a conveyor to a disintegrator of the cage-mill type.

While considering the degree of crushing required in the disintegrator, experience showed that if particles as large as 5/16 in. were permitted to be included in the final briquettes, breakages occurred in transit and a very porous and light briquette was produced. The briquette density should be controlled by reducing the upper limit of the particle size range. By choosing suitable grinding conditions, the approximate size analysis of the feed coke should be kept in line with Continental practice, i.e. >1/8 in., nil; 1/8-1/16 in., 10 per cent; 1/16-1/64 in., 90 per cent; and <1/64 in., minimum. The moisture content of the feed coke should be approximately 1·5 to 2 per cent.

The dry breeze feed is elevated to a basalt-lined surge hopper from which it is fed by means of a feeder table and conveyor to the briquetting machine or machines.

The Briquetting Machine. Two units operating in parallel were recommended in order to maintain continuity of operation.

The coke breeze entering the worm mixer is combined with liquid pitch to feed a vertical pug heated by live steam to a temperature of 98°C. From the pug the breeze/pitch mixture is fed by a tempering screw into the briquetting machine. The briquettes leaving the moulds are passed over a shaker screen to remove flash and fed into a final conveyor to the briquette storage. Each component is driven by its own individual gear drive and all units are connected to a central dust recovery system. The briquetting machines themselves are connected separately to this central system for removal of dust and fume.

In addition to discussions with three manufacturers of briquetting equipment in the U.K., France and Germany, some nine factories using machines of the designs being considered were visited. Outputs of these plants ranged up to 8,000 tons/day. The machine recommended was of German manufacture for the following reasons:

(*i*) Satisfactory arrangements for the feed of the material across the full width of the rolls easily and consistently.

(*ii*) The provision of suitable control equipment of an automatic type. This includes a sensing device between the rolls, level and temperature controls for the pug, level control of the feedbox and interlinking of the feeds at various points to the breeze/pitch ratio controller.

The pneumatic sensing device fitted between the bearings is an important improvement. The output from this device is a measure of the feed conditions and is used to adjust the main control settings. This enables even feed loading of the rolls to be maintained even though there is a variation in the texture of the supply from the pug. This means that the equipment can be used much nearer to its optimum operating point when the feed conditions are temporarily disturbed.

The optimum size of briquette appears to be related to a number of factors, e.g. degree of compaction, amount of binder required, wear encountered on briquetting rolls and evenness of heat treatment. With regard to heat treatment, the practical limits are not exactly known but appear to be of the order of 70 g. in weight with a smallest core-to-surface dimension of approximately 3/4 in. The size of briquette considered in this study was approximately $1\frac{3}{4}\times1\frac{3}{4}\times1\frac{1}{16}$ in.

Pitch. The basic decision was taken at the beginning to employ liquid pitch. Considerable difficulties exist in handling solid pitch, not the least of which is the health hazard to the workers engaged in handling it. Fortunately, supplies of pitch were available only two to three miles from the projected briquetting plant and it was therefore easy to arrange for transport of the pitch in steam-heated road tankers.

A pitch with a softening point of 72°-77°C. (R and B) seems most suitable for briquetting, with a 5° higher grade being employed in the summer. A typical sample examined had the following characteristics.

Softening point	72°-74°C. (K and S)
Flash point	187°C.
Viscosity (Redwood No. 1) at	165°C. 465 sec.
	175°C. 242 sec.
	212°C. 107 sec.

In general, coke-oven pitches are to be preferred to those from horizontal retorts which, in turn, are to be preferred to pitch from verticals. The fixed carbon content should be between 10 per cent and 16 per cent.

Hot pitch at about 175°C. would be pumped by steam-jacketed positive displacement pumps from the heated storage tanks to the worm mixer feeding the pug. A flow and return system of pipework would be employed in order to afford control of the amount of pitch being fed to the worm feeder. Steam tracing should be employed throughout.

BLENDING OF BREEZE WITH COAL

A further investigation was carried out some 12 months later which took into consideration the blending of coal with breeze and eventually the employment of coal alone. The addition of equipment to enable blending of 20-40 per cent of coal is straightforward. Simple addition of coal to the breeze feed before the dryer is not recommended, since if the moisture content of the two raw materials varies from time to time, blending will not be consistent. Two schemes employing separate drying streams for coal and breeze were considered. In the first scheme the dried, crushed coal was fed direct to the conveyor carrying the dried breeze to the pulverizer. The second scheme included separate drying and crushing of the coal, with the dried crushed product being added into the dried crushed breeze stream. This provides a more flexible arrangement with better control of the proportions of breeze and coal.

Study of the briquetting section, as applied to the use of coal, showed that the basic elements were unlikely to be different from those using breeze. A lower degree of abrasion was to be expected and thus a wider range of equipment could be employed. The only major alterations or additions that could be made would be additional handling, crushing and screening equipment to enable a wider range of coal grading to be employed.

HEAT TREATMENT

When breeze briquettes are subjected to low temperature heat treatment, complex physical and chemical processes take place. Some volatile matter is distilled off. Some solid and liquid components of the hot briquettes react oxidatively giving further chains of minor reactions. One such type of reaction leads to the addition of oxygen or oxygen-containing radicals to the carbon skeleton which makes up a 'coke molecule'. This skeleton which originates from the plate-like coal molecule lends itself to cross-linkages or polymerization.

From a practical point of view the quantitative result of the heat treatment process expressed as a loss of weight usually amounts to 2-5 per cent. From experimental results derived at the Central Research Establishment of the National Coal Board it was determined that heat treatment should be carried out between 200° and 300°C.

Most work of the commercial and semi-commercial nature on heat treatment appears to have been carried out in France and some three systems were investigated in that country. Of these three systems, the so-called Douai conveyor type plant appears to be the most satisfactory.

At the Douai works operated by the French national undertaking dealing with coal, Charbonnage de France, a successful plant consisting of four units has been operating continuously for over five years, with a total throughput of approximately 25 tons/hr per stream. This plant consists of four tunnel ovens through which the briquettes are taken in trucks. No attempt is made to recover the tail gases from the furnaces and these are merely brought to wet scrubbers and discharged to stack. At this works a pilot unit has now been developed which would operate continuously by means of a belt conveyor. The exact details of this plant are not available for publication, but a relatively simple means is employed in dealing with the various zones of temperature change during the treatment process as the conveyor moves through the tunnel kiln. There is considerable saving of capital in employing the conveyor system rather than trucks.

The process appears to operate satisfactorily using either breeze or coal briquettes bound with pitch. A range of coals has been employed at

Douai, mostly with an ash content of 8-9 per cent and employing pitch binders, the pitch originating from oil or coal. The principal variables to be noted during the treatment process are the temperature and the oxygen content of the circulating gas in each section of the plant. The heat treatment conditions for the Douai process must be oxidizing. This indicates that the heat treatment process is not a mere distillation effect but also that oxygen-containing complexes are formed at the surface which serve to improve the burning properties of the fuel.

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Production of Smokeless Fuel and Metallurgical Coke by Heat Hardening in an Oxidizing Atmosphere and Subsequent L.T.C.

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The new process for oxidizing hardening with subsequent carbonization is suitable for the production of metallurgical coke or strong and highly reactive semicoke in the form of lumps or briquettes for industrial purposes and domestic heating. The process is suitable for universal application and can be applied to low volatile coals and semicoke fines of various origins. By this oxidizing treatment, the agglomerates prepared with a binder are transformed into a fuel burning with little smoke. Subsequent carbonization converts this fuel into a tar-free and smokeless product.

By suitably varying the operating conditions, and by proper selection of the size of briquettes, fineness of the material and type of binder, it is possible to produce a domestic fuel or metallurgical coke meeting the specifications. The process can be applied in ovens of simple design and robust construction if combined belt and shaft hardening or hardening in Spülgas oven with oxidizing stage are used.

Coarsely-grained coals and high volatile coal fines can be treated by the two-stage process involving Spülgas or flash carbonization, briquetting of semicoke with the tar from carbonization, oxidizing hardening and final carbonization for the production of shaped coke. Preliminary tests in pilot plant with anthracite fines and semicoke of various origins have shown that by suitable selection of the operating conditions, metallurgical coke meeting the specifications with regard to strength, porosity and reactivity can be produced.

SMOKELESS FUEL AND METALLURGICAL COKE

There is a great demand for smokeless fuel for domestic and metallurgical purposes. The main requirements of such fuel are adequate strength, resistance to abrasion and proper size, apart from low ash and sulphur contents.

For domestic heating, the prime considerations are smokeless combustion, suitable reactivity and low ash and sulphur content, to prevent pollution of air and to cope with the specific design of the heating stoves. While particle size and strength are of lesser importance, the customers in some European countries have special wishes regarding the shape and appearance of the fuel, because traditionally they are used to black shining coal briquettes of neat appearance.

The specifications for metallurgical coke are much more severe and generally cover the following properties[3]:

Adequate size, low moisture ash and sulphur contents, high strength, determined chiefly by the shatter and abrasion tests, high carbon content, i.e. high degree of devolatilization, relatively high ignition temperature and a moderate reactivity to ensure its complete combustion to carbon dioxide, resulting in the development of high temperatures. Degree of devolatilization, porosity and particle size of the coke should be suitably correlated so as to favour the above tendency.

The highest requirements are demanded from metallurgical coke for foundries. Next follows coke for blast furnaces and low-shaft furnaces. The relevant properties are given in Table 1.

TABLE 1—METALLURGICAL COKE PROPERTIES [1,3,14]

	FURNACE COKE		FOUNDRY COKE	
	Ruhr District	England	Ruhr District	England
Size	above 80 mm.	not below 1 in. (5% tolerance)	above 80 mm.	closely-graded sizes in the limits 2-8 in.
Moisture, %	3-5	uniform, not over 3	ca. 3	not above 2
Ash, %	below 10	uniform, not over 10	ca. 9	7-10
Sulphur, %	0·9-1·2	as low as possible 0·9-1·7	ca. 1·0	0·7-1·2
Volatiles, %	1-2	1·5	0·8	below 1·0
Calorific value, kcal./kg.	6300-7000	..	ca. 7000	..
Strength, kg./sq. cm.	100-150	..	..	..
Micum test, %	above 80	..	85	..
Porosity, %	40-50	..	50	..

The above figures are based on coke obtained from conventional process of coking bituminous coals in coke ovens and must be regarded as maximum requirements for other metallurgical coke production processes. These properties should be met as far as possible and as experience has shown, other processes like the two-stage process for the production of shaped coke are also capable of furnishing coke of this quality. When the available coal does not give coke of above quality, a lower quality coke might also be tolerated by suitably arranging the metallurgical processing steps. An example is the low-shaft furnace or of iron ore reduction processes, such as the Krupp-Renn Process which require only fine-grained fuels.

The coke oven produces high temperature coke in externally heated ceramic ovens, at temperatures of 900-1000°C. The byproducts recovered are gas with a gross calorific value of 4500 kcal /Nm^3 and liquid hydrocarbons including tar and benzole. The main product is devolatilized lumpy coke of high mechanical strength. The large particle sizes meet the specifications (Table 1) and are therefore used as blast furnace coke for the smelting of iron ores and as foundry coke for the smelting of iron in cupola furnaces. This process depends on the availability of ample supplies of typical coking coals (Type IV, V A—V D). However, the resources of these coals are limited and vary considerably from country to country. On the other hand, the deposits of high volatile coals (Type VI A, VI B and VII) which are weakly caking are much larger[2]. Extensive work has been carried out all over the world with a view to find methods which permit the utilization of these coals for coke production by suitable blending.

Another direct process for the devolatilization of bituminous coal is low temperature carbonization (l.t.c.) which furnishes coke of lower mechanical strength, but of higher reactivity. The coal is heated in ovens of various designs to 550°-850°C. whereby it is converted to semicoke having a certain residual volatile content. The byproducts include tar and light oil (substantially undecomposed when using 'Spülgas' ovens) and gas with a calorific value of 2000 kcal./Nm^3 when using 'Spülgas' ovens and of 8,000 kcal./Nm^3 when using externally heated ovens. L.t.c. either occurs in externally heated ovens with ceramic or metallic walls, similar to the classical coking process, or in internally heated 'Spülgas' ovens. Amongst these processes, the LURGI 'Spülgas' process, originally developed for the processing of lignite has been successfully applied in numerous plants in Europe and elsewhere for the carbonization of bituminous coals. The process is limited to the treatment of non-caking or weakly caking coals with a caking index to Damm of 12, but it has an advantage, in that it permits the construction of large-sized units. Moreover, the same unit can produce semicoke of high and low volatile contents by applying temperatures of 600°C. and 950°C. respectively.

Where coal of suitable particle size is available, it can be charged to the process directly, as for example in the l.t.c. pilot plant at Regional

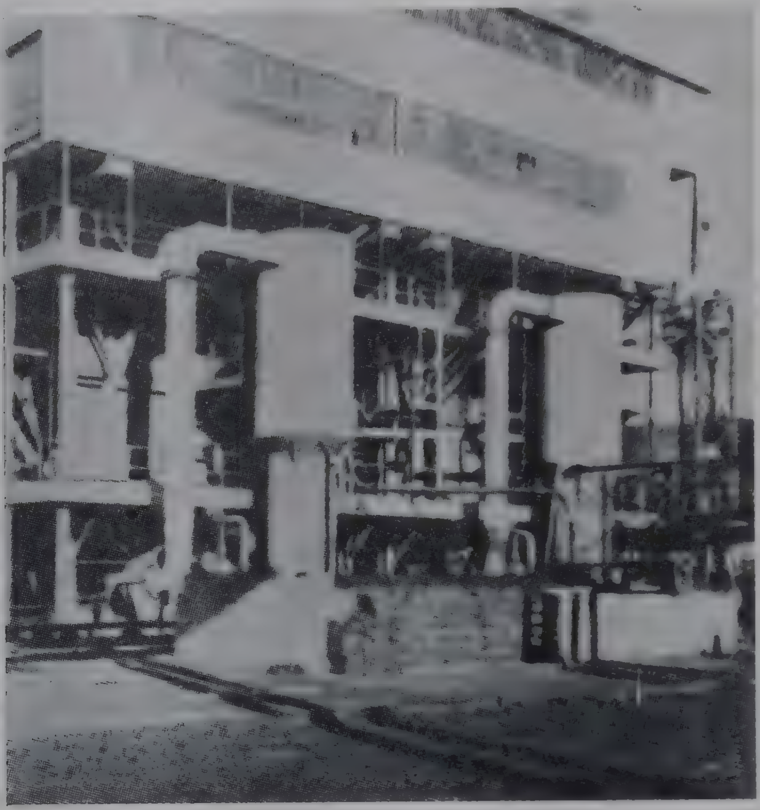

FIG. 1—LOW TEMPERATURE CARBONIZATION PLANT AT MODDERFONTEIN/ SOUTH AFRICA WITH SPRAY COOLERS FOR COOLING GAS

Research Laboratory, Hyderabad, which has been producing 'kolsit' for use as smokeless fuel in place of charcoal. Another 'Spülgas' carbonization plant consisting of two industrial units, each with a capacity of 420 tons per day is in operation in South Africa and produces semicoke with 3-4 per cent volatiles from non-caking lumpy bituminous coal at 950°C. The semicoke is gasified with oxygen and steam to yield water gas which is used in a synthesis plant for production of urea (Fig. 1).

Another large l.t.c. plant consisting of 10 'Spülgas' ovens is processing briquettes at a temperature of 850°C. The briquettes were prepared from fine-grained weakly caking Upper Silesian coal using sulphite waste liquor as binder. The coke briquettes were properly fused and of extremely high strength with a volatile content of 2-4 per cent and were gasified in water gas generators in a synthesis plant.

For the carbonization of bituminous coal alone, 29 industrial units have so far been built in different countries with a total capacity of nearly 3 million tons of semicoke per annum.

Similar to the classical coke-oven process, l.t.c. at medium and high temperatures also depends more or less upon the properties of the bituminous coal charge and in particular on its caking properties, to produce a fused coke of adequate resistance to abrasion. The countries with limited resources of coking coal are faced with the problem of utilizing their available reserves of high volatile and non-caking coals, which are unsuitable for coking for the production of metallurgical coke. This problem can only be tackled by applying processes other than the usual coking process. Apart from the hot briquetting method, which implies the briquetting of coal in plastic condition and which is applied at present in large pilot plants in England and the Netherlands[7,8], the process of heat hardening in an oxidizing atmosphere has been specifically developed for the processing of tar- or pitch-bound bituminous coal briquettes or coke briquettes, with or without subsequent carbonization.

While hot briquetting depends on certain properties of the coal and requires the maintenance of a very narrow temperature range, the oxidizing hardening method is suitable for universal application. It can be applied to coals with low volatile content, such as anthracite and low volatile steam coal (Types I—IV) and to breeze from semicoke or even high temperature coke. When the coal charge has a low volatile content, hardening and carbonization or coking can be accomplished in one processing step. A two-stage process is required for coals with high volatile content, the first stage producing the semicoke in fine-grained or pulverized form, the second stage comprising oxidizing hardening and possibly carbonization or coking. With this arrangement, the quality of the end product is largely independent of the properties of the feed coal.

The production of uniformly sized coke briquettes is of advantage in the subsequent processing units, such as blast furnaces and electric furnaces, which will result in their increased output.

Apart from the particle size, the porosity and reactivity of the coke can be varied within certain limits, by adopting suitable methods for preparation, briquetting and carbonization, so that the coke may satisfy the specific requirements of the metallurgical processes.

HISTORICAL DEVELOPMENT OF HEAT HARDENING IN AN OXIDIZING ATMOSPHERE

The method of heat hardening in an oxidizing atmosphere, originally applied to the production of smokeless briquettes from low volatile coal, such as anthracite and lean coal, was first developed towards the end of the twenties. A German patent[15] was granted to Trent Process Corporation, New York, covering the oxidizing treatment of pitch-bound briquettes by a two-stage process using process gas of a different temperature and oxygen content in each stage. The temperature range for oxidizing treatment laid down in this patent is still applicable today. A few years later, Koppers acquired a patent on a process[16] which provides for oxidizing treatment of briquettes prepared substantially from caking bituminous coals and pitch binders, prior to coking to prevent softening and caking together of the briquettes. At about the same time, Compagnie Générale Industrielle Carmaux, France[4], applied an oxidizing pretreatment with oxygen-containing flue gases to briquettes prepared from caking coal with 28-29 per cent volatiles and pitch binders, to prevent softening and disintegration of the briquettes during subsequent carbonization in externally-heated vertical chamber furnaces. The oxidizing treatment in the two last mentioned processes occurred batchwise.

In the thirties, Lurgi Gesellschaft für Wärmetechnik first applied oxidizing treatment in connection with the carbonization of lumpy caking bituminous coal and developed a special design of its well-known 'Spülgas' oven, incorporating an oxidizing and a thermal treatment zone. This oven was in operation over several years[5] and it had been the intention to use it also for the treatment of pitch-bound briquettes.

After World War II, work on oxidizing hardening was resumed by Houilléres du Bassin du Nord et du Pas de Calais, France to make smokeless fuel for domestic heating from the lean coals available in northern France. This work finally led to the production of smokeless briquettes, called 'anthracines', which are prepared by treating pitch-bound lean coal briquettes with oxygen-rich circulating flue gases at temperatures up to 350°C. The process was first applied in a tunnel-type furnace and later in a conveyor belt furnace. Tunnel-type furnaces are arranged for substantially automatic operation. The conveyor belt furnace operates continuously. In the year 1960, the output of the plants, which still used chiefly tunnel-type furnaces was roughly 600,000 tons of smokeless briquettes[6,8].

In the United States, the heat hardening technique is mainly applied to the production of briquettes from fluid coke, which is recovered from thermal conversion of high-boiling oils into low-boiling fractions. The hardening step is performed by immersing the briquettes in hot finer fluid coke particles on a moving grate. The second step (thermal treatment) occurs in a shaft furnace[12].

In view of the limited resources of coking coals available in Poland, efforts were made there very early towards the production of metallurgical coke from the large deposits of coals suitable for l.t.c. A process was developed by 'Institut für Chemische Kohleveredlung Zabrze' which produces metallurgical coke from non-caking and weakly caking coal[2,9,10] by the oxidizing hardening of briquettes prepared from semicoke and heavy tar fractions. A large-scale pilot plant was started several years ago to produce large quantities of hardened semicoke briquettes of different size, which were successfully used in small-diameter cupola furnaces.

At about the same time, research work was carried out in Australia regarding the practicability of producing metallurgical coke for cupola furnaces from sub-bituminous Collie coal, applying a two-stage process. The first stage includes the production of semicoke which is briquetted with coal-tar or wood-tar binder, hardened by oxidation and finally carbonized at 600°C. in the second stage. In cooperation with the Australian Government, Lurgi prepared a project study for the installation of a commercial plant (based on this process) which included 'Spülgas' ovens for carbonization and tunnel-type furnaces for oxidizing hardening, due to the

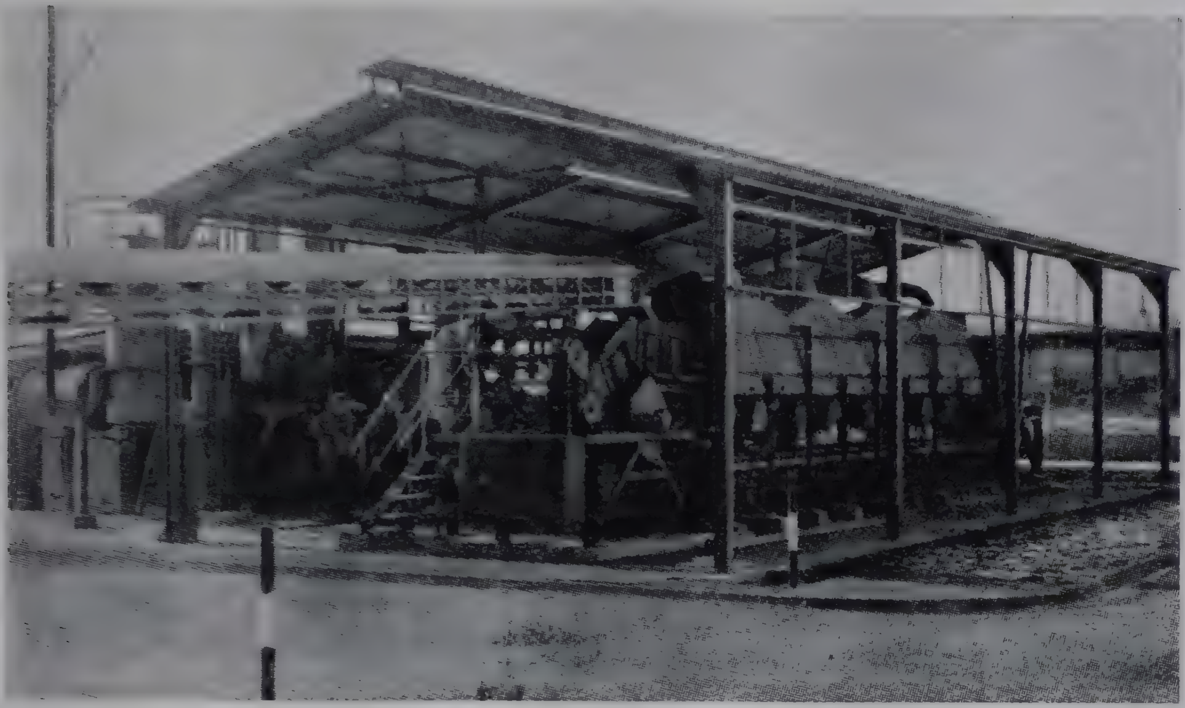

FIG. 2—PILOT PLANT FOR OXIDIZING HARDENING OF BRIQUETTES

small capacity of the plant of 20,000-40,000 tons of coke per annum and the 650 g. size requirement of the briquettes. The design of the tunnel-type furnaces had been developed by Lurgi on the basis of their experience in the construction of tunnel-type furnaces for the processing of oil shale.

For further study of the problems connected with the process and equipment, the 6 tons day carbonization pilot unit existing in Lurgi's research station at Frankfurt (Main) was supplemented by additional facilities, including a belt hardening unit for continuous oxidizing hardening, with a capacity of 10 tons/day (Fig. 2).

PRINCIPLE OF OXIDIZING HARDENING

The oxidizing hardening technique implies oxidizing thermal treatment of the briquettes with air or combustion gases having a high oxygen content. The effect of this oxidizing treatment is similar to that of pitch blowing, the object being the increase of the softening point. The effect is intensified by the fact that the tar is in contact with the oxidizing agent on a large surface. The technique therefore involves blowing of the binder on the surface of the particles of the briquetting material (anthracite or semi-coke). By the blowing of tar to pitch, it is possible to obtain below the boiling point of the tar, a strong product, mainly responsible for the mechanical strength of the coke and which has similar properties as pitch coke insofar as any separation of tar distillates during carbonization does not occur. The unstable chemical properties of tar have a favourable effect on the process. Tar from 'Spülgas' carbonization has very good polymerizing properties, whereas coke oven tar is less suitable. Wood-tar or similar products are quite suitable for oxidizing hardening as also a number of tar products which are recovered from flash carbonization of coal fines by the Lurgi-Ruhrgas Process.

The briquetting pressure is only of secondary importance. It should be so selected that the individual particles of the briquettes are brought into proper contact. The application of higher pressure will not result in any material saving of binder since it is not the briquetting pressure but the amount of the "cement" in the briquette that is of importance for the strength of the finished product. In most cases, the briquettes can therefore be produced on ordinary roll presses. Briquettes, which must have a very dense structure, should be prepared on large-diameter roll presses.

The briquetting material generally consists of 0-2 mm. sizes, which correspond to the normal material used for preparing pitch-bound briquettes. If a high density is required, 0-1 mm. sizes are also used. In this case, the amount of binder increases by 20-30 per cent. The variation of particle size and amount of binder permits control of the porosity of the finished product and its adaptation to the requirements of the metallurgical processes.

The amount of binder for the production of briquettes to be heat hardened depends on the type and properties of the briquetting material. For the hardening of briquettes produced from anthracite, they should contain 7-8 per cent binder. 'Spülgas' semicoke briquettes from young bituminous coals require 10-12 per cent binder and brown coal semicoke of porous structure 12-15 per cent. Extremely fine coke from the fluid bed requires still higher percentage of binder.

The size of the briquettes depends on the specific use. For domestic heating, egg-shaped briquettes of 25-50 g. weight are preferred, while larger sizes are generally required for industrial purposes, such as blast furnaces and cupola furnaces. Briquettes for blast furnaces should have a minimum weight of 250 g. whereas briquettes of 600-900 g. are required for cupola furnaces. There is, however, the tendency now to use smaller sizes for blast furnaces and to reduce the size of the burden accordingly. Experience has shown that the output of blast furnaces can be increased considerably by charging them with uniformly shaped fuel of small size. From the viewpoint of the hardening treatment, briquettes of small size (50-150 g.) are preferable, since the hardening time increases with increasing size of the briquettes, resulting in higher cost of the hardening equipment and higher production cost per ton of finished product. The weight should not possibly exceed 300 g.

The main parameters of the hardening process are treating time and temperature. Hardening proceeds from the outside to the inside of the agglomerate at a rate of roughly 0·5 cm. per hour[10]. The process is exothermic, the amount of heat liberated being so great that it can make the process self-sufficient in heat requirements. In accordance with the low speed of hardening, the treating time is 2-3 hr for 50 g. egg-shaped briquettes and up to 7 hr for larger briquettes of 600 g. depending upon the temperatures to be applied. With increasing hardening time, there is the danger of coal or coke also being attacked by oxygen; unduly long duration of hardening should therefore be avoided.

The hardening temperature depends on the nature of pitch and coal used. Coals of low reactivity, such as anthracite, permit the application of high temperatures of 350-380°C. while highly reactive semicoke must be hardened in a lower range of 200°-250°C. Also, the permissible oxygen content varies between 6 and 12 per cent, depending upon the reactivity of the coal.

Moreover, the properties of the basic material play an important part, particularly in the case of semicoke. The application of high carbonization temperatures of 800°-900°C. appears to create a favourable effect, because it was found that further shrinkage does not occur during hardening and subsequent devolatilization. Obviously high carbonization temperatures also favourably affect the oxidation process, as stated in the Polish and Australian papers[2,9,10,11].

Due to the absorption of oxygen, the loss in weight of the agglomerates during oxidizing treatment is low, the yield, being about 97 per cent.

COMBINED HARDENING AND CARBONIZATION

Due to the slow progress of hardening from outside to inside of the agglomerate, complete removal of the tarry components of the binder can only be achieved by greatly increasing the treating time, when coal or coke itself would be attacked. In the case of 50 g. egg-shaped briquettes, there is generally a residual tar content of 1-2 per cent after a treating time of 2-3 hr depending upon the nature and amount of the binder. The hardening process is often deliberately so conducted that the core of the briquette is not detarred completely. In this case, the fuel is not free from tar and burns with little smoke, because the tar vapour developing inside the fuel have to pass through the hardened outer layer, whereby they are subjected to secondary decomposition. The French Anthracine Process is based on this principle. Although the smoke formation is largely reduced, it is not completely eliminated.

For all applications, where tar-free, smokeless fuel is required, as, for instance for automatic central heating systems in European countries and for metallurgical purposes, an additional carbonization step must therefore be included. A carbonization temperature of 500°-600°C. will generally be sufficient, although higher temperatures might be preferable, when properly fused coke with low volatile content is required.

The following two schemes can be applied for this combined process:

Single-Stage Scheme. Oxidizing hardening of briquettes prepared from anthracite or lean coal fines, with subsequent carbonization in the 'Spülgas' oven.

Two-Stage Scheme. 1. Combined 'Spülgas' carbonization and oxidizing treatment with final carbonization. 2. Combined Lurgi-Ruhrgas flash carbonization of coal fines and oxidizing treatment with final carbonization.

The single-stage process involves briquetting of the anthracite and lean coal fines with about 8 per cent binder, with subsequent oxidizing treatment and carbonization. These coals may be blended with higher volatile coals, such as steam coal and fat coal, with a saving of a certain proportion of binder. The proportion of blend should not exceed 40 per cent in the case of steam coal, and 20 per cent in the case of fat coal, in order not to affect the surface properties of the coke and to prevent fissuring.

The fuel thus produced is chiefly used for domestic heating, in which case a carbonization temperature of 550°C. will be adequate. In some

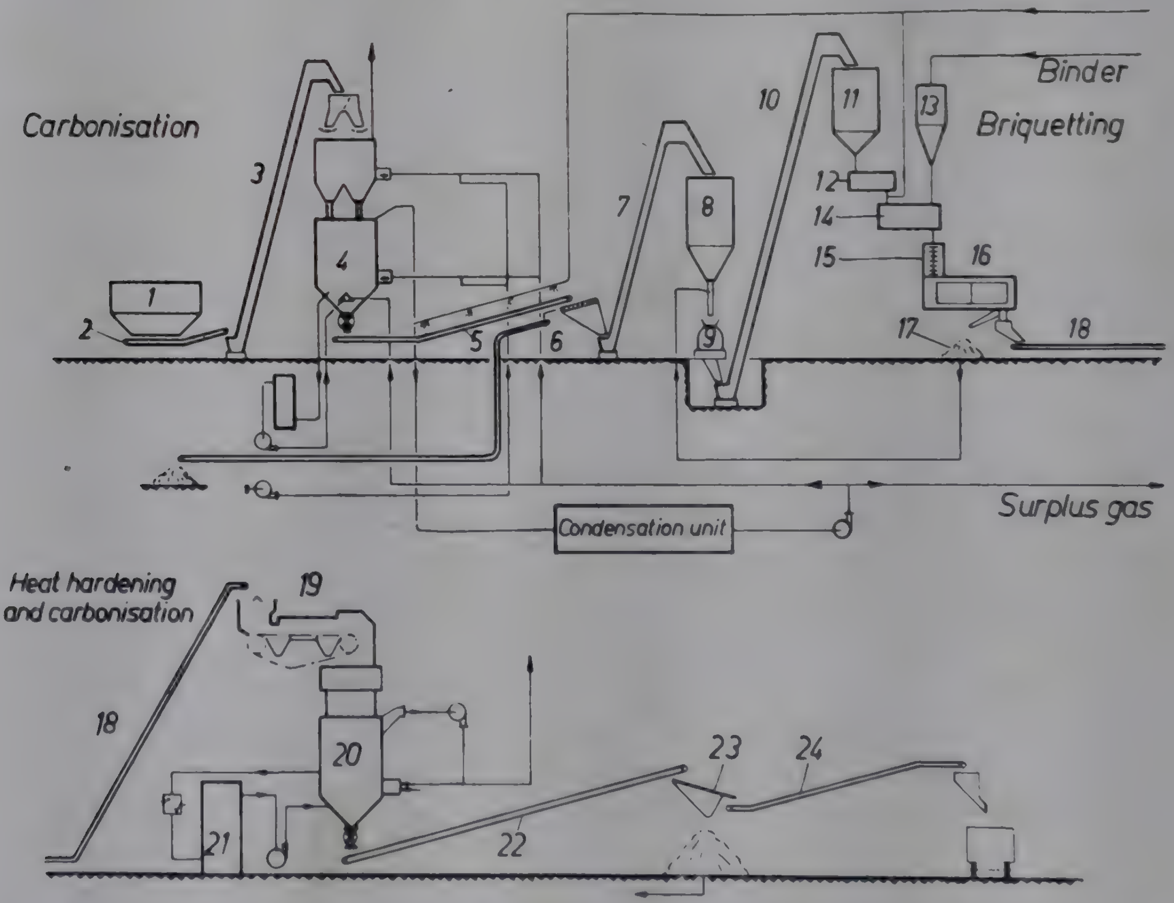

FIG. 3—FLOWSHEET FOR THE PRODUCTION OF METALLURGICAL COKE FROM BITUMINOUS COAL IN A COMBINED MOVING-GRATE AND SHAFT-UNIT: (1) Raw coal bunker (2) Rubber belt to bucket elevator (3) Bucket elevator (4) Carbonizer for raw coal (5) Char cooling and conveyor belt (6) Screening and conveyor belt for coarse char (7) Bucket elevator (8) Coke bunker (9) Char grinding mill (10) Steep chain elevator (11) Intermediate storage bin for pulverized char (12) Proportioning device (13) Pitch vessel (14) Turbo mixer (15) Dough mixer (16) Briquetting press (17) Discharging chute for waste briquettes (18) Belt for curing plant (19) Curing belt (20) Carbonizer (21) Cooler for char (22) Rubber belt (23) Screen for separation of briquette fines (24) Rubber belt to store

countries, such as Germany, the application of this process is rather attractive, because the product commands a high selling price. The loss in heating value is only about 200 kcal./kg. related to the feed material. The yield varies between 92 and 94 per cent, depending upon the carbonization temperature applied. The product burns without smoke and is suitable both for heating stoves and automatic central heating systems.

By the application of higher carbonization temperatures, particularly when treating briquettes with caking blend constituents, the fuel produced will have properties comparable to metallurgical coke (Fig. 3).

The two-stage process operates as follows:

Lumpy coal is carbonized in the Lurgi 'Spülgas' oven at a high temperature to obtain a high degree of devolatilization. The larger sizes of the semicoke may be marketed direct for special applications or used as reducing agent in electric furnaces.

The fines of the semicoke or sometimes the complete size range is then crushed to a particle size of 0-1 mm. or 0-3 mm. The wear in the crusher depends upon the properties of the coal and the carbonization temperature applied. In the case of semicoke prepared at 700°C. the rate of wear is only about half of that produced at 900°C. which is still only one-third of the wear experienced during the crushing of metallurgical coke from coke ovens.

The crushed coke is briquetted with the heavy tar from 'Spülgas' carbonization, and the resulting agglomerate is subjected to oxidizing hardening, followed by a final carbonization step in the 'Spülgas' oven. This carbonization can be done at medium or high temperatures, depending upon the specific use of the finished product, but it should not be higher than the temperature in the first treating step, in order to provide for an adequate strength of the coke.

The process is applied to lumpy non-caking or weakly caking coals of high volatile content. The finished product consists of strong lumpy shaped coke containing 2-4 per cent volatiles, suitable for metallurgical processes. The high percentage of shrinkage of the coal particles in the first treating step permits the use of relatively little binder. The addition of water will also contribute towards a saving in binder. The binder requirements range from 10-15 per cent related to the coke, so that feed coal having at least 8 per cent tar can be processed without the addition of external binder.

The second process under the two-stage scheme mentioned above is based on coal fines which are carbonized in a fluidized bed by the Lurgi-Ruhrgas process. The arrangement of the process is illustrated in Fig. 4.

The heat necessary for carbonization is supplied by partial combustion of the pneumatically circulated coke. The introduction of the heat into the carbonization zone by a solid heat carrier is of advantage insofar as the heat transfer is extremely good resulting in high yield of tar (much above the figures of the Fischer carbonization assay). The carbonization gas with

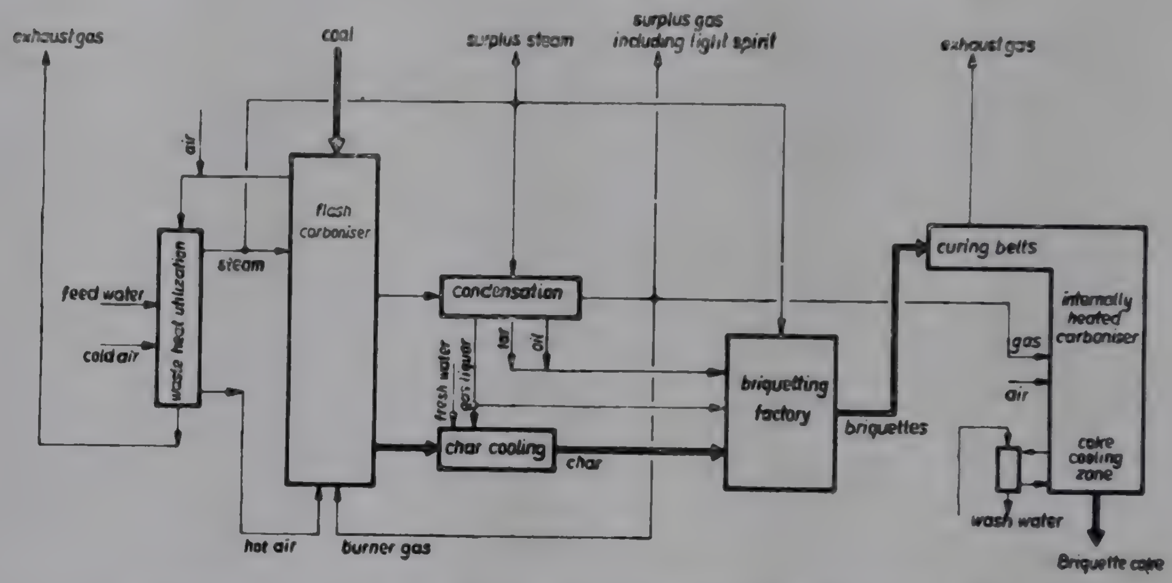
exhaust gas
coal
surplus steam
surplus gas including light spirit
exhaust gas
air
flash carboniser
steam
feed water
cold air
waste heat utilization
condensation
tar
oil
fresh water
gas liquor
char cooling
char
briquetting factory
briquettes
curing belts
internally heated carboniser
gas
air
coke cooling zone
wash water
Briquette coke
hot air
burner gas

FIG. 4—FLOWSHEET FOR THE PRODUCTION OF METALLURGICAL-BRIQUETTE COKE FROM COAL FINES

a relatively high calorific value of 4500 kcal./Nm^3 is suitable for use as town gas.

The process can be applied to non-caking and caking coal fines of 0-3 mm. or 0-6 mm. size so that crushing is generally not required.

The heavy tar fraction from flash carbonization is used as binder, possibly with the addition of a certain proportion of middle oil. Briquetting occurs on ordinary roll presses, the same as in the preceding case. The amount of binder ranges from 10 to 20 per cent depending on the nature of the coal, because some types of coal disintegrate easily, giving very fine coke, thus requiring addition of a high percentage of binder. These higher requirements are in most cases compensated by the higher tar yields. The briquettes are heat hardened and carbonized, the resulting product being a very dense fused coke particularly when a high proportion of binder has been added. Depending upon the type of final treatment, the finished coke can be used for domestic heating or for metallurgical purposes.

HARDENING AND SECOND CARBONIZATION STEP

It was earlier mentioned that hardening proceeds at a relatively low speed. Moreover, heating of the briquettes to the hardening temperature of 200°-300°C. causes softening of the binder, which solidifies again as oxidation proceeds. Hence, the strength of the briquettes goes down to a minimum during the initial hour of hardening treatment, as can be seen from Fig. 5.

These characteristic features of the hardening process require the use of special equipment. Due to the softening of the briquettes during the initial stage, the briquettes must be treated under steady conditions and in a fairly thin layer. Tunnel-type furnaces were therefore first used, where the briquettes to be hardened are filled in waggonets having a ground

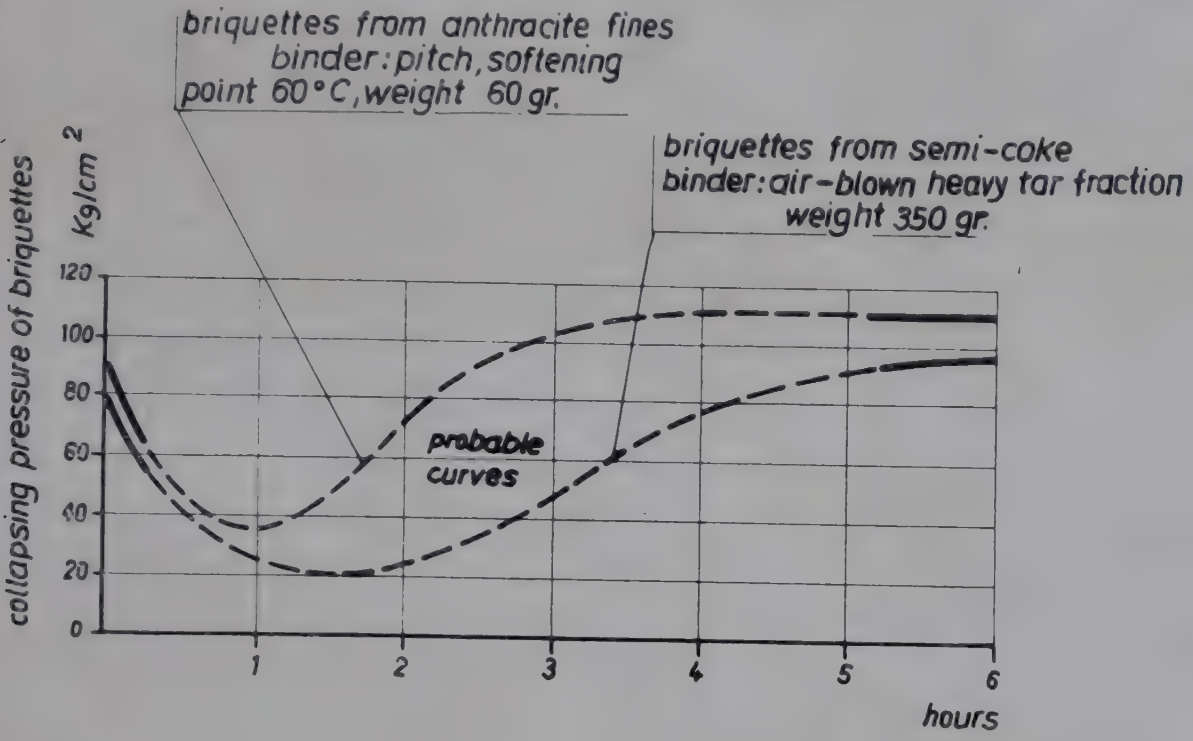

FIG. 5—COLLAPSING STRENGTH OF BRIQUETTES DURING OXIDIZING HARDENING

floor area of 2 × 3 m. and a bed height of 0·5—1 m.[6], depending upon the capacity of the plant, the strength of the briquettes and the type of binder used. Such a tunnel-type of furnace was for instance provided for the heat hardening of semicoke briquettes prepared from Australian Collie coal (Fig. 6).

The length of tunnel furnaces for industrial application may be rather considerable. For instance in France, tunnel-type furnaces with a length of up to 60 m. are used for the production of so-called anthracene briquettes (Fig. 7), with a capacity of 300 tons day. The treating time of the briquettes in these furnaces is about 5½ hr[6]. Other installations use hardening belts with a bed depth of only 0·5 m. and a width normally not exceeding 2 m. for reasons of design. This again requires the construction of plants of considerable length, although the investment cost will be lower than for tunnel furnaces, due to the lower weight of construction. The subsequent heating to 550°C. or more requires additional equipment, either 'Spülgas' ovens or externally heated ovens. This heat treatment cannot be accomplished in the hardening equipment, except in the case of the tunnel-type furnace, provided that the waggonets are made of special material and the maximum temperature does not exceed 550°C.

In view of the high cost of such installations, which require separate equipment for hardening and carbonization, Lurgi started experiments to find a less costly process which would furnish a technically favourable solution and which first of all would permit hardening and carbonization in a single unit. The following two schemes have been developed:

1. Combined conveyor belt and shaft hardening.
2. Hardening in the upper part of the shaft of the 'Spülgas' oven.

The first process is based on the fact that solidification of the briquettes proceeds from outside to inside resulting in formation of a strong crust even after a relatively short time, which permits subjecting of briquettes to higher strain occurring on their way to and during their passage through a shaft furnace. The length of the belt is so selected that the collapsing strength of the briquettes at the end of the belt is sufficient for gently charging them direct to the shaft. Conveyor belt and shaft are assembled in one unit which renders operation and servicing easy (Fig. 3). The length of the belt ranges from 7 to 12 m. depending upon the properties of the briquettes.

The hardening in a shaft oven is based on the design of the normal 'Spülgas' oven. By suitably rearranging the gas flow, the predrier has been so designed that the briquettes enter the treating zone in cold condition, where they are treated with the oxidizing gases flowing in co-current. In the lower

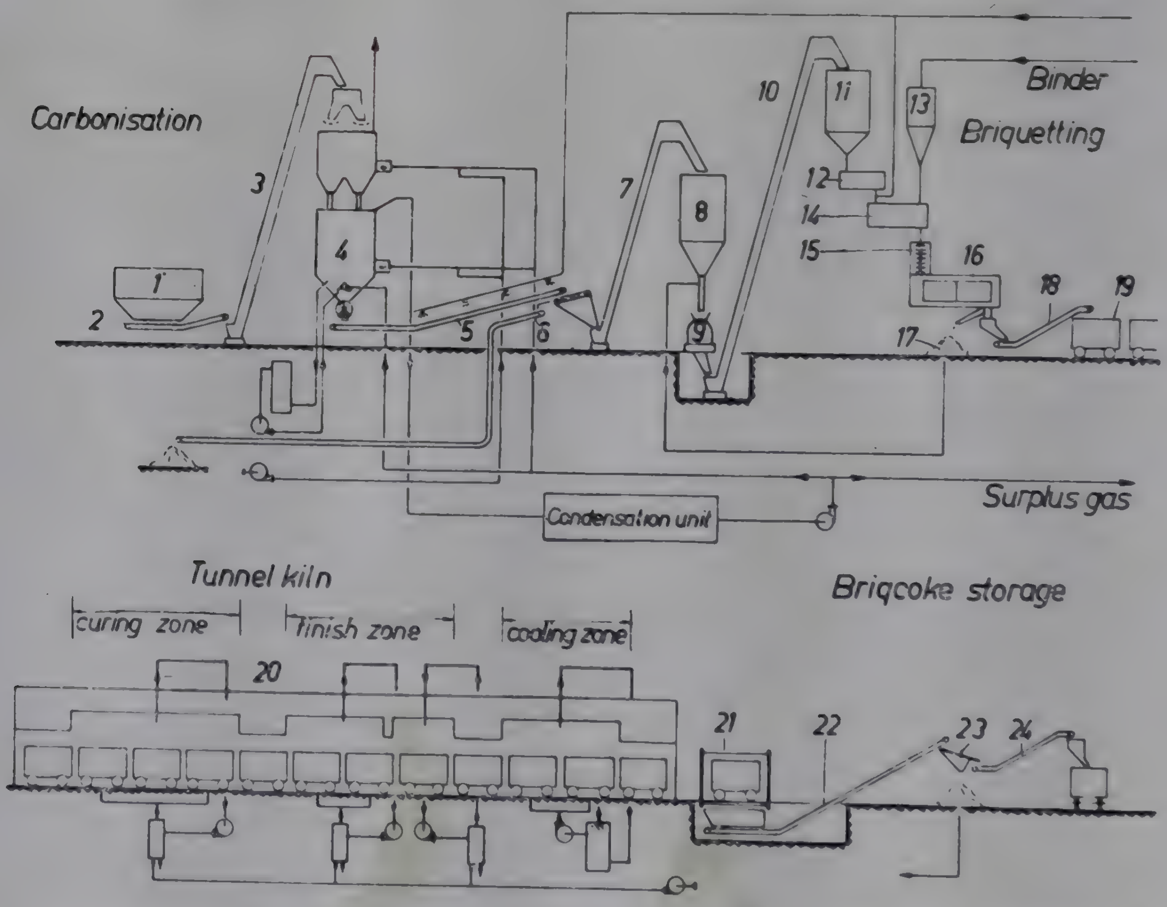

FIG. 6—FLOWSHEET FOR THE PRODUCTION OF METALLURGICAL COKE FROM SUB-BITUMINOUS COAL IN A TUNNEL KILN: (1) Raw coal bunker (2) Rubber belt to bucket elevator (3) Bucket elevator (4) Carbonizer for raw coal (5) Char cooling and conveyor belt (6) Screening and conveyor belt for coarse char (7) Bucket elevator (8) Coke bunker (9) Char grinding mill (10) Steep chain elevator (11) Intermediate storage bin for pulverized char (12) Proportioning device (13) Pitch vessel (14) Turbo mixer (15) Dough mixer (16) Couffinhal briquetting press (17) Discharging chute for waste briquettes (18) Loading belt for trucks (19) Trucks (20) Tunnel kiln (21) Truck tipper (22) Rubber belt (23) Screen for separation of briquette fines (24) Rubber belt to store

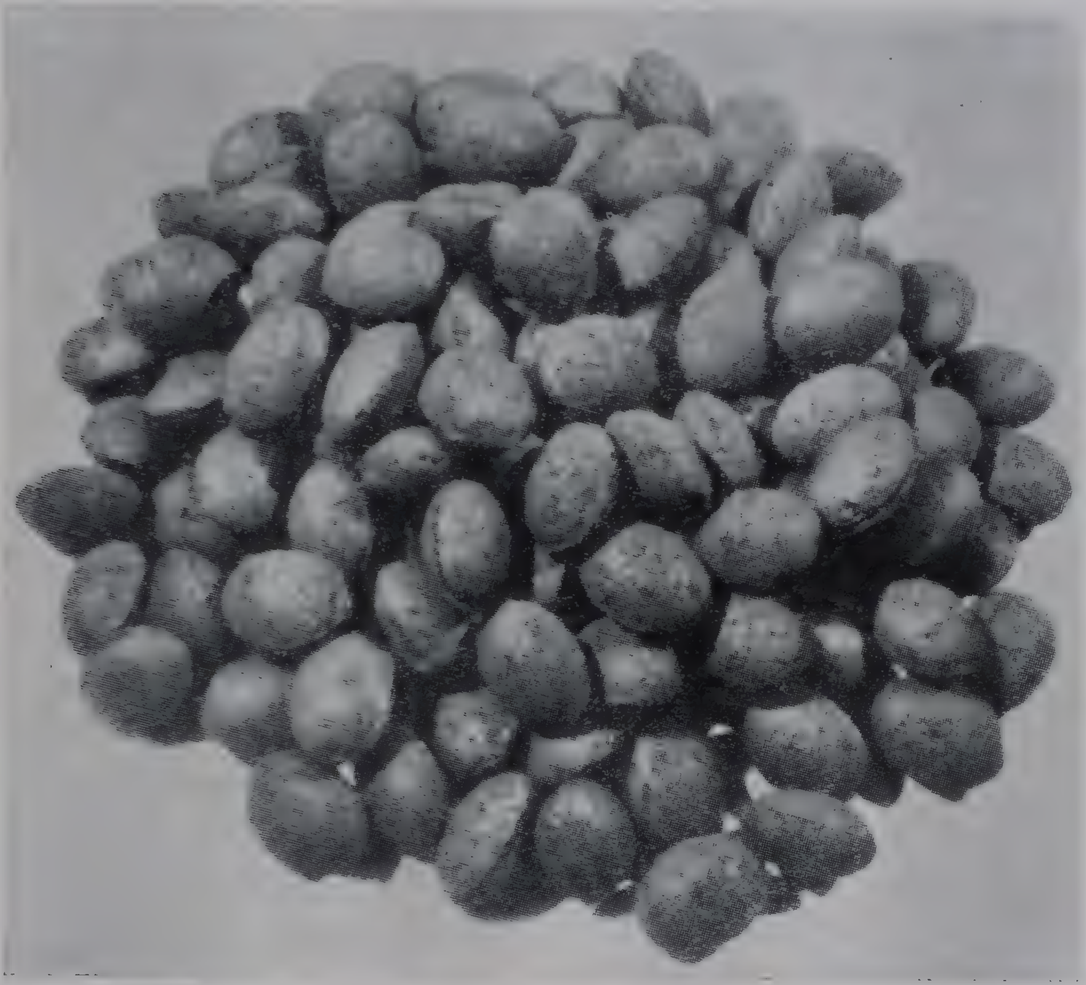

FIG. 7—BRIQUETTES FROM ANTHRAFINES OXIDIZED AND CARBONIZED IN THE LURGI-SPUELGAS OVEN

part of the oxidizing zone counter-current treatment may be applied as and when required. The process can be applied in large-capacity plants to the treatment of quite a number of pitch-bound briquettes, preferably those with a binder of higher softening point. The appearance of the finished briquettes differs only very little from that of belt-hardened briquettes, proving the practicability of this method.

PILOT PLANT FOR OXIDIZING HARDENING AND CARBONIZATION

The various factors, which influence oxidizing hardening and carbonization had to be studied in more detail on a technical scale. Lurgi Gesellschaft für Wärmetechnik mbH who are running an extensive technical pilot plant at Frankfurt comprising equipment for drying and briquetting with and without binder (roll presses and ring roll presses), and one 'Spülgas' carbonizer for 6 tons/day, decided in 1959 to supplement this with equipment for oxidizing hardening, which includes the following: one discontinuous

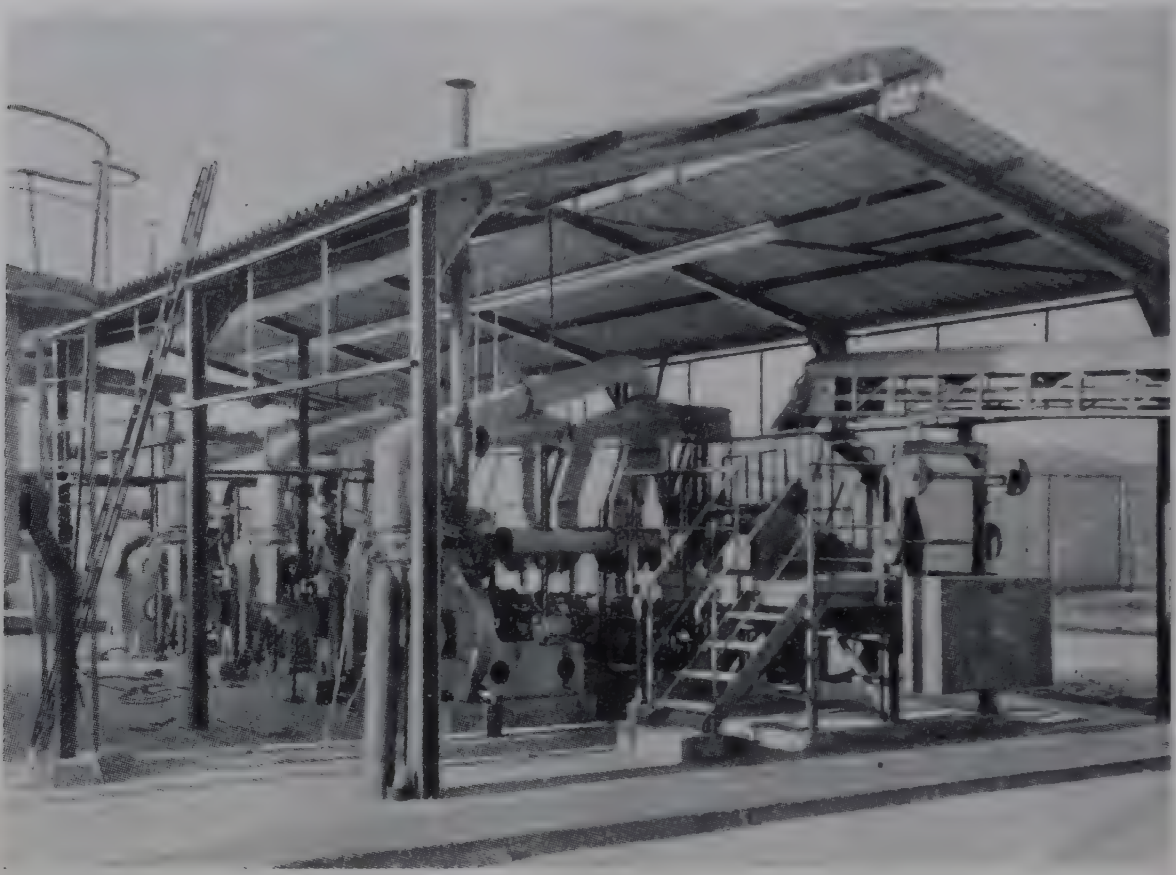

FIG. 8—PILOT-CONVEYOR-BELT FURNACE FOR OXIDIZING-HARDENING (capacity 10 tons/day)

hardening apparatus for hardening and carbonization tests, one continuous hardening belt for 10 tons/day, one hardening stage which is incorporated in the predrier shaft of the 'Spülgas' oven.

The conveyor belt plant is illustrated in Fig. 8.

The plant consists of a 0·5 m. wide and 12 m. long grid belt with high side walls, which provides for a briquette bed depth of 60 cm. The belt is sub-divided lengthwise into 4 zones, which are sealed off from one another by elastic sealing elements.

The first zone serves as heating zone and initial hardening stage, the two following zones being the second and third hardening stage and the last being the cooling zone. This sub-division into four zones was chosen to permit wide variation in test conditions.

When mere oxidizing hardening is required, the briquettes are treated on the belt, whereas they are charged to the 'Spülgas' oven, if they have to be carbonized subsequently. This arrangement was selected also for flexibility.

The carbonizing oven incorporates the latest advances with regard to the flow of gas. Carbonization temperatures can be varied within the range of 550° and 950°C. The oven is also equipped with cooling gas cycle for intensive cooling of the coke (Fig. 9).

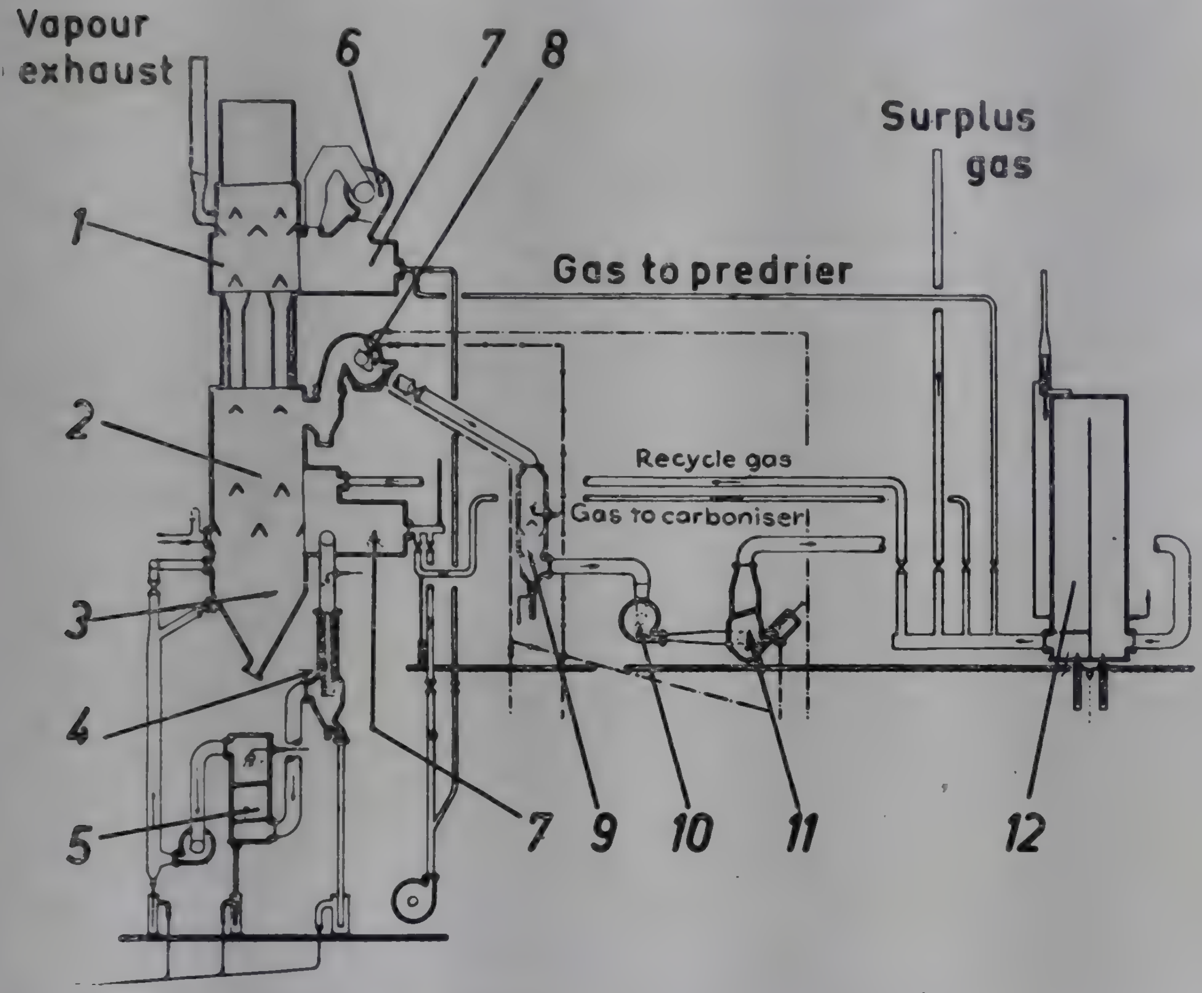

FIG. 9—L.T.C. PLANT FOR THE PRODUCTION OF DRY COKE FROM NON-CAKING LUMP COAL: (1) Drying zone (2) Carbonizing zone (3) Coke cooling zone (4) Venturi cooler (5) Spray cooler (6) Predrier fan (7) Combustion chamber (8) Dust separator (9) Precooler (10) Hot gas fan (11) Hot tar washer (12) Main cooler

The installation of the hardening equipment was completed by the end of 1960 and numerous tests have been conducted on the hardening and carbonization of pitch-bound briquettes prepared from anthracite, lean coal as well as from 'Spülgas' semicoke and coke from flash carbonization. The total quantity of the material tested so far amounts to 150 tons.

Table 2 gives a summary of test results which may serve as a guide for the performance figures obtainable from oxidizing hardening and subsequent carbonization.

The test results clearly demonstrate that the combined processing method furnishes a product of much higher strength as compared to oxidizing hardening treatment only. The Micum drum test indices of anthracite briquettes hardened in the shaft furnace meet the specifications for blast furnace coke.

The new process for oxidizing hardening with subsequent carbonization is suitable for universal application for the production of metallurgical coke or strong-shaped semicoke and is largely independent of the nature of the feed coal or coke fines.

TABLE 2—TEST RESULTS FROM OXIDIZING HARDENING OF BRIQUETTES PREPARED FROM ANTHRACITE FINES AND 'SPÜLGAS' SEMICOKE

	ANTHRACITE			'SPÜLGAS' SEMICOKE 7% VOLATILES		
Size, mm.		0-2			0-2	
Binder						
Percentage		7			11·5	
Softening point, °C.		60			44·5	
*Condition of tested briquettes	a	b	c	d	e	f
Proximate analysis						
Moisture, %	1·6	0·7	1·3	4·4	1·6	0·6
Ash (775°), %	8·6	9·3	9·4	5·5	5·2	6·0
Fixed carbon, %	78·1	79·6	83·6	78·1	84·8	90·8
Volatiles, %	11·7	10·4	5·7	12·0	8·4	2·6
Fischer assay at 520°C.						
Moisture, %	1·6	0·7		4·4	1·6	
Carbonization liquor, %	0·2	0·6		0·3	0·1	
Tar, %	4·2	1·3	tar-free	8·0	1·1	tar-free
Coke, %	92·9	94·7		86·5	94·8	
Gas and loss, %	1·1	2·7		0·8	2·4	
Weight of briquettes, g.	60·0	56·1	56·1	21·6	20 0	19·0
Yield, %	..	97·0	93·0	..	92·7	86·0
Collapsing strength, kg.	85·0	104·0	211·0	..	190 0	205·0
Density, g./cm³.	1·22	1·23	1·26	..	1·16	1·17
Abrasion test	(Micum drum test to DIN 51712)					
Feed above 30 mm. DIN						
+M 30				89·4%		
—M 10				9·2%		

* a, d—green; b—hardened; c—hardened and carbonized; e—hardened over 3 hr; f—hardened and carbonized at 800°C.

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DISCUSSION

Dr F. A. Oetken: I have pleasure in adding a few words on the method of briquetting South Arcot lignite.

At present a large installation is under construction at Neyveli to produce coke from lignite. In the new plant the lignite before carbonization will be briquetted by means of extrusion presses. Such presses have been designed basing on the experiences gained in Central and Western Germany.

The lignite of South Arcot differs in physical and chemical aspects from the soft brown coal in Central and Western Germany. Earlier tests, which were made have shown that it is possible to produce briquettes from extrusion presses for making solid coke. A still harder coke can be produced when the briquette is made by ring-roll-presses as they have been developed by Lurgi. In this new process the lignite is first dried in a shock-drier using an inert gas and then briquetted in a ring-roll-press.

When the decision on the Neyveli project was being taken, it was found on economic considerations that it was not possible to make use of the ring-roll-press. However, at a later stage when the Neyveli project may be enlarged and the coke used for the reduction of Salem ores, it should be useful to consider the application of the ring-roll-press.

With this method it would be possible to produce a coke sufficiently hard for the reduction in a low shaft furnace. Regarding the method to produce iron from Salem ore, it should be mentioned that new methods for the direct reduction of Salem ore have been invented in recent years. For the industrial development of South India this might be of special importance.

Among the different methods for direct reduction I would like to refer to the combined work of Hamilton Steel Works (Canada) and Lurgi (Frankfurt). By this method the reduction is carried out in a rotary kiln by means of gas and a small percentage of coke. The coke to be used can be less hard than in the case of the low shaft furnace. Therefore, this new method might be of particular interest in the treatment of Salem ore.

SECTION TWO

Low Temperature Carbonization of Non-caking Coals and Lignites

Low Temperature Carbonization of Coal in a Fluidized Bed

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The main requirements for low temperature plant are outlined, with special reference to the use of the fluidization technique.

Constructional materials, particle-size distribution, dust control, heat supply, agglomeration problems, byproduct recovery and instrumentation are discussed in the light of experience gained with a small experimental plant of 50 lb./hr nominal capacity.

Experimental results are presented to illustrate the effects of carbonizing temperature, particle residence time and fluidizing gas upon the yields and properties of the products.

High temperature carbonization of coal has been used commercially for more than a century to produce town gas and metallurgical coke. By contrast, low temperature carbonization (l.t.c.) has been much less widely practised, partly because of technical difficulties and partly because of uncertain markets for the products.

The aims of recent research work on l.t.c. have been governed by the differing national and local needs of the countries concerned. Smokeless domestic fuel has been the chief objective in both India[1–5] and the United Kingdom[6–8], although the reasons for this emphasis are different in the two countries.

In the United States[9–14] and Canada[15] interest has been shown in the l.t.c. of bituminous coals and lignites combined with the use of the resulting char as pulverized fuel in power-station boilers. The object in this case would be to recover low temperature tar for conversion into more valuable products such as liquid fuels and chemicals and thus to reduce the cost of the solid fuel fed to the boilers. Developments along these lines are, however, at a standstill at present because economic processes are not yet available for commercial treatment of the tar.

In France[16–18], Japan[19–22], and Australia[23–25] l.t.c. has been extensively studied as a means of producing low-volatile char suitable for blending with high-volatile coals in order to improve the quality of metallurgical coke for foundry cupolas and blast furnaces. Fluidized-bed carbonization of coal at temperatures of the order of 800°C. may be used to produce low-volatile fuel for sintering iron ores. Such developments as these should be of special interest to India, to ensure that the expanding steel industry will make the best use of the limited supplies of coking coals.

Char might also serve as a raw material for total gasification, but usually there would be no incentive to use it in preference to raw coal for this purpose.

FEATURES REQUIRED IN A LOW TEMPERATURE CARBONIZATION PLANT

Both technical and economic factors are involved in selecting the most suitable type of l.t.c. plant for given conditions. The main economic requirements for successful operation of such a plant are the existence or ready creation of secure outlets for the various products, particularly for the char which is the major product by weight. Profitable outlets are also desirable for the other products, especially the tar and gas, but commercial operation might be possible in some circumstances by charging all costs to certain marketable commodities only—in the extreme case to the char alone.

If the primary aim is the production of a readily-ignitable smokeless lump fuel, its size, shape, volatile-matter content and reactivity are major considerations. For such a purpose fixed-bed processes are favoured because they enable advantage to be taken of any coking properties possessed by the feed coal and this may compensate for the relatively low heat-transfer rates. Nevertheless, as in a process being developed in Great Britain by the National Coal Board[8], fluidized-bed carbonization can be used for the first stage of manufacture of smokeless lump fuel. If, on the other hand, the product is not required in lump form, fluidized-bed processing offers the great advantage of high rates of heat transfer with consequent savings in capital and operating cost. Moreover, for metallurgical coke-making and firing of large boilers, char in granular or powdered form is preferable to lumps.

DESIGN AND OPERATION OF A FLUIDIZED-BED CARBONIZATION PLANT

L. t. c. of coal on the fluidized-bed principle has been studied in recent years in various types of laboratory apparatus[1,4,26,27] and pilot plants[5,6,9–21,23,24]. An account is given below of design and operating experience at the Division of Coal Research, C.S.I.R.O., with a small experimental plant (nominal capacity, 50 lb. of coal an hour), the flowsheet of which is shown in Fig. 1. Further details of the plant have been published elsewhere[23].

Materials of Construction. The parts of the plant operating at temperatures of 400°-650°C. in particular the carbonizer, are made of mild steel, but at higher temperatures the use of this material is inadmissible because it is attacked by oxygen and carbon. Hence stainless steel was chosen for the casing and baffles of the gas preheater, and Inconel-sheathed electrical elements for the preheater, the carbonizer, and the temperature-control system for the walls of the cyclones.

Bronze gate valves have been used successfully in all locations where coal and char are handled, including the hot-char recycle line.

Particle-size Distribution of Coal and Char. Control of particle-size distribution is comparatively simple in a system where the fluidized-bed consists of particles of a catalyst which are being continually recirculated. But where fresh reactant particles are constantly being admitted and subjected to chemical and physical changes, as in fluidized-bed carbonization of coal, the balance between the various size fractions is continually being upset.

Under these circumstances closed-circuit grinding of the feed coal minimizes the production of unnecessarily fine particles, but even with such grinding it is impossible to produce the optimum distribution of sizes for

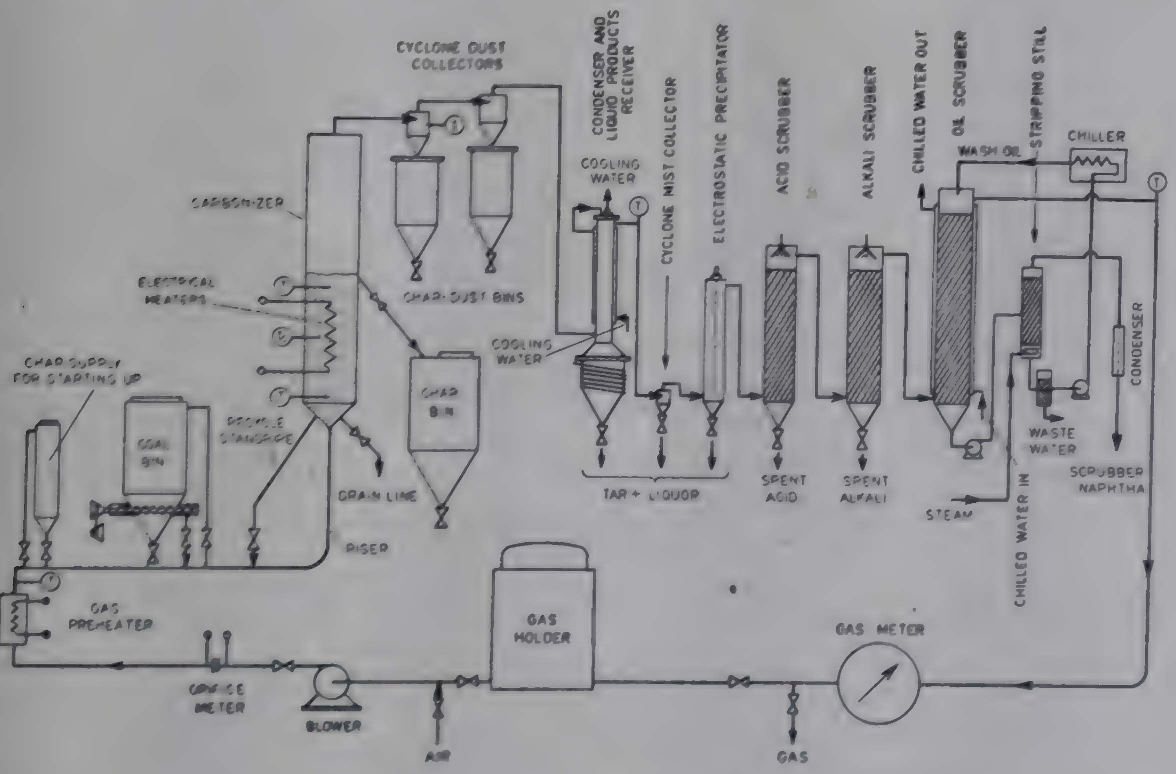
CYCLONE DUST COLLECTORS
CONDENSER AND LIQUID PRODUCTS RECEIVER
CYCLONE MIST COLLECTOR
ELECTROSTATIC PRECIPITATOR
ACID SCRUBBER
ALKALI SCRUBBER
CHILLED WATER OUT
OIL SCRUBBER
STRIPPING STILL
CHILLER
WASH OIL
T
COOLING WATER
CARBONIZER
ELECTRICAL HEATERS
CHAR-DUST BINS
COOLING WATER
CHAR SUPPLY FOR STARTING UP
COAL BIN
RECYCLE STANDPIPE
CHAR BIN
DRAIN LINE
TAR + LIQUOR
SPENT ACID
SPENT ALKALI
STEAM
WASTE WATER
SCRUBBER NAPHTHA
CONDENSER
CHILLED WATER IN
RISER
GAS PREHEATER
GAS HOLDER
GAS METER
ORIFICE METER
BLOWER
AIR
GAS

FIG. 1—FLOWSHEET OF EXPERIMENTAL PLANT: T—Temperature measurement point (indicator/recorder); Tc—Temperature controller (Reproduction by Courtesy of Institute of Fuel,

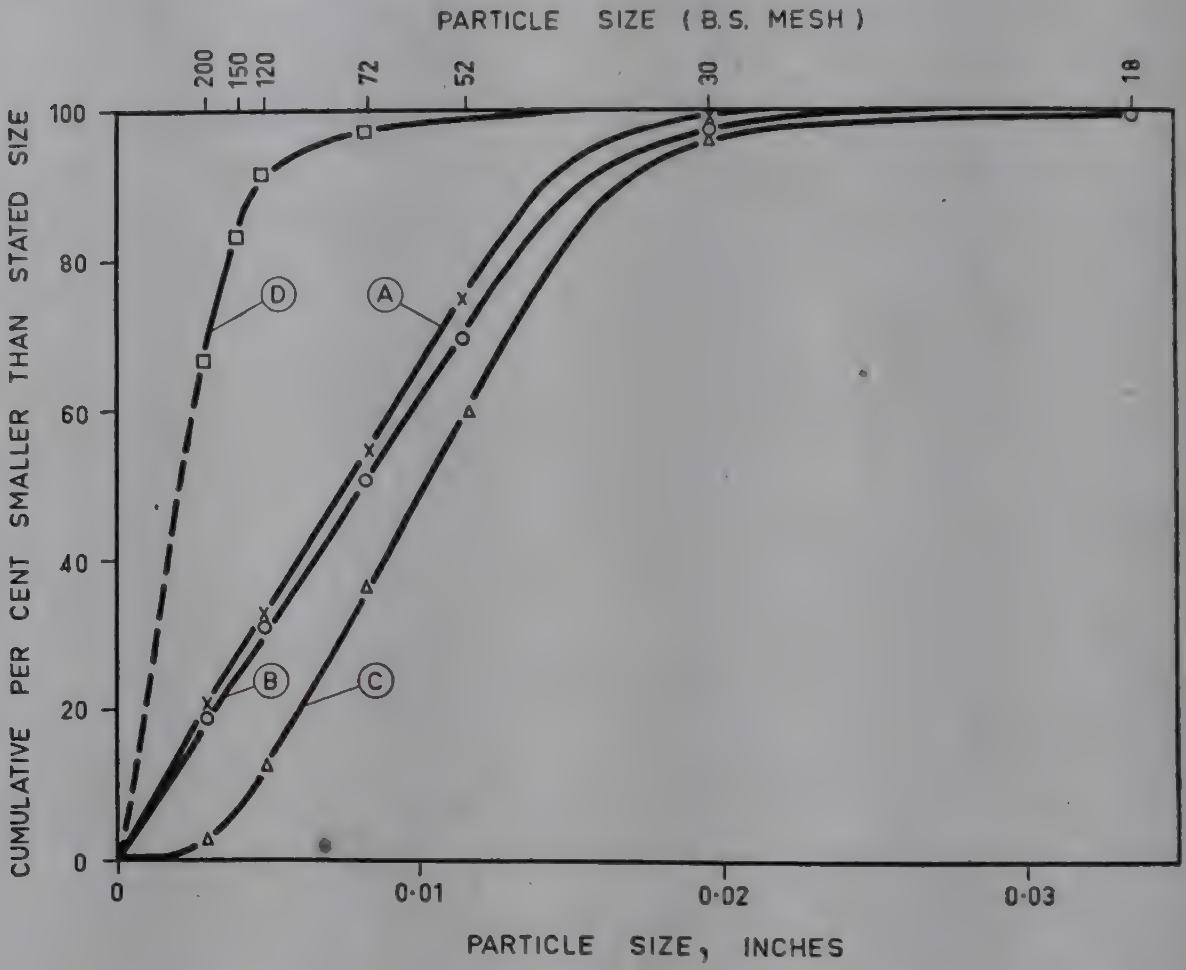

FIG. 2—PARTICLE SIZE DISTRIBUTION FOR COAL AND FOR CHAR PRODUCED FROM IT (WALLARAH SEAM COAL): (A) Feed coal (B) Total char (C) Overflow char only (D) Cyclone char only

fluidization. Usually, too much fine material is produced and this is removed comparatively rapidly from the bed by entrainment in the fluidizing gas.

Comparison of curves (A) and (B) in Fig. 2 shows the general increase in particle size which occurs when the feed coal is carbonized and curves (C) and (D) illustrate the partial separation of fine and coarse particles caused by the elutriating action of the fluidizing gas upon the bed. As shown by curve (D) the elutriated particles are very fine. It can therefore be expected that they will be fully carbonized after only a short residence time in the bed.

Theoretically, particles become entrained in a rising gas stream when their free-falling terminal velocity is less than the gas velocity; so that, at a given fluidizing velocity, particles smaller than a certain critical size will be elutriated, while larger particles will remain in the bed. Examination of curves (C) and (D) in Fig. 2 shows, however, that under typical fluidized-bed conditions the separation is not sharp. In practice, a small amount of coarse material is collected in the cyclones and a little fine material persists in the bed for long periods of fluidized operation. This may be attributed to local variations in gas velocity within and above the bed.

TABLE 1—FORMS OF CHAR PRODUCED BY LOW TEMPERATURE CARBONIZATION OF WALLARAH SEAM COAL

Carbonizing temperature	500°C.	
Fluidizing gas	Air	
Mean residence time of particles	34 min.	

	No pre-treatment	Elutriation	
		With one cyclone	With two cyclones
Percentage of char accounted for as:			
Coarse char (overflow)	70·2	80·0	77·9
Fine char (No. 1 cyclone)	17·4	16·6	17·5
Fine char (No. 2 cyclone)	*	*	3·5
Carry-over (visible deposits)	11·9	2·2	nil
Carry-over (in tar) (by diff.)	0·5	1·2	1·1

*Only No. 1 cyclone was installed at the time these tests were carried out.

Dust Control. The entrainment of fine carbonized particles in the outgoing gas stream is not an objectionable feature of fluidized-bed operation provided the entrained particles are removed from the gas stream before the tar is condensed. This removal is essential to prevent the tar becoming contaminated with insoluble char dust, and, in serious cases, to avoid blockages in the byproduct recovery plant. The entrained particles are of a wide range of sizes, the finest being virtually impossible to recover in conventional dust-collecting appliances.

The dust problem may be attacked in two different but complementary ways: (*i*) by eliminating or at least minimizing the admission of excessively fine dust to the carbonizer; (*ii*) by employing efficient dust-collection systems.

Admission of fines can be minimized by appropriate grinding techniques, as mentioned earlier and by removing any fines which are unavoidably produced. Such removal may be accomplished by (1) air classification (2) screening or (3) fluidized-bed elutriation. Of these methods, the first method is probably the most suitable for industrial application because it enables large quantities of solids to be handled easily and gives a fairly sharp size "cut". While the last method does not permit such a sharp separation of sizes, experience at the Division of Coal Research[23,24] has shown that it greatly reduces the amount of dust carried over into the byproduct recovery system.

Table 1 shows the differences in char recovery for three runs under the same carbonizing conditions but at different stages of development of the experimental plant. Before elutriation of the feed coal was adopted and when only a single dust-cyclone was in use, much dust was carried over and deposited in the condensing system and connecting pipework. Later, the adoption of elutriation and the installation of a second cyclone greatly eased the dust problem.

The proportion of the feed removed by elutriation varies with the type of coal and the grinding treatment it has received. Much of the material removed can be used for other purposes—for instance, as pulverized fuel for boiler firing. Typical elutriation results for two coals are shown in Fig. 3.

Heat Supply. Development of l.t.c. has been retarded by the fact that coal has a low thermal conductivity and therefore the heat-transfer rate in the carbonizer has tended to be poor, with consequent adverse effects on thermal efficiency and plant throughput. Low thermal conductivity greatly restricts the rate of heat transfer by conduction, in accordance with the well-known Fourier equation:

$$\frac{dQ}{d\theta}=kA\frac{dt}{dx}$$

where $dQ/d\theta$=rate of heat transfer (Btu/hr), k=thermal conductivity [Btu/(hr) (ft^2) (°F./ft)], A=cross-sectional area of the heat path (ft^2), and dt/dx=temperature gradient (°F./ft).

The efficiency of the l.t.c. process is restricted also by the fact that, to keep within the required temperature limit, it is necessary to work at a low temperature gradient. As is clear from the Fourier equation, in systems where the heat is transferred mainly or entirely by conduction the rate of heat transfer may only be increased by making A as large as practicable and x, the length of the heat path, as small as possible.

Supplementing conduction with convection gives a more uniform temperature as well as improved heat transfer. Convection may involve (*i*) forced movement of gases through the coal and/or (*ii*) movement of the coal particles themselves. Of these (*i*) may be applied to fixed beds of lump coal and both (*i*) and (*ii*) occur in fluidized beds. Whereas the value of convection lies in maintaining reasonable temperature uniformity throughout the bed, heat transfer into each individual particle can occur only by conduction. Fourier's equation shows that conduction into small particles under fluidized-bed conditions can be quite rapid, because A then corresponds to the total surface area of the particles and is large; whilst x corresponds to the nominal radius of the particle and is small. This may be seen from Table 2, which gives values of A and x for a range of spherical particles. These values may be used to estimate a mean radius and specific surface for any known mixture of sizes, such as those represented in Fig. 2. Coal particles are, of course, angular rather than spherical and moreover, changes in shape and size take place during the carbonization process while heat transfer is occurring. The tabulated values may be corrected easily

TABLE 2—CHARACTERISTICS OF SPHERICAL PARTICLES

Particle size (B.S. mesh)	Radius of particle ($\times 10^{-4}$ ft)	Specific surface of particle (sq. ft/lb.)*
18	14·00	25·4
30	8·21	43·4
52	4·83	73·7
72	3·46	102·9
120	2·04	175·0
150	1·71	208·0
200	1·25	285·0

*Based on true specific gravity of 1·35.

by means of a shape factor to allow for the form of the original coal, but the changes occurring during carbonization are too complex for the true values to be determined. However, the main interest lies in the orders of magnitude of the values, because they show that the possible rate of conduction into the particles is so large that it is unlikely to be the limiting factor in heat transfer.

The heat required for fluidized-bed carbonization may be supplied either by direct combustion of a portion of the char or tar within the bed (internal heating) or by heat transfer from some source of energy outside (external heating).

With internal heating, air is used as the fluidizing gas and it is possible to adjust the flow rates of air and coal so that the heat generated by combustion equals the heat required for carbonization plus the heat losses from the plant. The air-flow rate is fixed by the range of fluidizing velocities appropriate to the size distribution of the coal, while the coal feed rate is bound with the desired mean residence time of the particles, and with the depth and diameter of the fluidized bed. If necessary, combustion may be moderated by adding either steam or combustion products to the fluidizing air; but the first alternative increases the liquor yield without increasing its value and raises the cooling-water requirements of the condenser, whilst the second reduces the calorific value of the gas. A more convenient arrangement for experimental purposes is to use a slightly lower air rate than necessary for full internal heating and to provide a supplementary heat supply from submerged electrical heaters controlled by the bed temperature.

By appropriate adjustment of carbonizing conditions and suitable plant design[23] either the char or the tar may be used as the principal fuel for internal combustion. At 460°-500°C. the char does not burn readily and the oxygen in the fluidizing air is mainly consumed in burning the tar as it is released in the bed. On the other hand, at 550°-600°C. the char burns so easily that the oxygen is largely consumed in the char recycle line and little oxygen remains for reaction with the tar.

External heating is necessary when gases other than air are used for fluidization, for example fuel gases from other processes or gas from the fluidized-bed carbonization itself, recycled after purification. Submerged electrical heaters may not be economical commercially, but several other ways of applying external heating have been suggested[23]. The advantages of an externally-heated carbonizer are that there is no loss of char or tar and the gas produced has a high calorific value.

The choice between internal and external heating is essentially a matter of economics based on local requirements. If the production of char is the main interest and the other products are of marginal value, internal heating with preferential combustion of tar is the most suitable arrangement because it demands only the simplest of plant and yields the maximum of char and the minimum of byproducts.

Agglomeration Problems. The plastic properties which coal develops during carbonization vary greatly from one coal to another. Those coals which develop high fluidity during carbonization are difficult to process in fluidized beds because the particles tend to stick together, forming lumps of coke. Table 3 summarizes the relevant properties of a number of representative Australian coals which have been carbonized successfully in

TABLE 3—TYPICAL COMPOSITION AND PLASTIC PROPERTIES OF SOME AUSTRALIAN COALS

NAME OF SEAM	V.M. (dry, ash-free)	ASH (dry basis)	B.S. SWELLING NUMBER	GRAY-KING COKE TYPE	GIESELER MAX. FLUIDITY (dial divisions per min.)*
Big Ben	38·0	9·6	4	E/F	41
Excel	15·7	9·3	5	C	0·8
Greta	44·4	7·2	4	G4/G5	590
Liddell	40·1	8·1	6-½	G1/G2	84
Lithgow	37·7	12·8	1	E	33
Wallarah	34·0	13·0	½	C	0·5
Yallourn	52·4	1·8	..	..	..
Young Wallsend	39·2	14·4	5-½	G_3	180

*At heating rate of 3°C. per minute.

the fluidized bed; the great variation in fluidity is noteworthy. Coals with a fluidity as high as 10,000 Gieseler dial divisions per minute are mined commercially in Australia.

The fluidity increases markedly with the heating rate, and therefore where the heating rates of individual particles are of the order of hundreds of degrees per minute, as in a fluidized bed, actual fluidities are much higher than the values given in Table 3. It is impossible with a Gieseler plastometer to determine fluidities under such conditions, but estimates based on extrapolated data[24] show that even for Wallarah seam coal values equivalent to 2000 dial divisions per minute may be attained at a heating rate of 500°C./min. This explains why it is quite normal for even poorly coking coals to soften and swell during fluidized-bed carbonization and to form soft, puffy particles with surfaces which are smoother and more rounded than those of the original coal particles. The plastic properties of coals are also accentuated by heating in the presence of hydrogen, a condition which exists when recycle gas or other mixtures containing hydrogen are used as the fluidizing medium.

The problem of agglomeration in fluidized beds can be attacked in four distinct ways:

(*i*) *Rational Choice of Coal.* Agglomeration should be avoided as far as possible by carbonizing non-coking coals, thereby also ensuring that coking coals are not wastefully used for purposes for which their plastic properties are a liability rather than an asset.

(*ii*) *Dilution.* It is an advantage to mix highly coking coals with a non-coking material, as this reduces the agglomerating tendency to a safe level. The best noncoking additive for this purpose is the char produced by the process itself, because contamination of the product is thereby avoided. The proportion of char required depends upon the coal used and is somewhat less than would be expected on the basis of laboratory agglutinating tests, because of the effects of attrition between particles in fluidized systems. After initial experiments with mixtures of coal and char, Lang, Smith and Bordenca[14] introduced a circulation system which enabled hot char to be continuously blended with the incoming feed coal. A similar char-recycling system has since been successfully used with Australian coals[23]. The effect of dilution is to minimize collisions between coal particles while they are in the plastic stage and so prevent the formation of large lumps of strong coke. Small lumps, consisting of only a few particles, cause little trouble and the same applies to mechanically weak aggregates, which readily break down again to single particles. Whether char recycling is used or not, it is advantageous to admit the feed coal to the carbonizer as a suspension in the fluidizing gas to ensure rapid dispersal of the particles through the bed.

(*iii*) *Oxidation.* The coking power of coals is drastically reduced by mild oxidation and this treatment has been applied to coal before fluidized-bed carbonization[9,10,13,14]. However, it is undesirable from economic point of view since the extra processing step adds to the overall cost of carbonization and also reduces the tar yield. Lang, Smith and Bordenca[14] suspected that oxidation of the feed particles contributed to the success of their char-recycling system. Experience with several coking coals at the Division of Coal Research is consistent with this view, because agglomeration occurred in some runs when using recycle gas but not when fluidizing with air under otherwise identical conditions.

(*iv*) *Chemical Additives.* Various other substances are capable of reducing the coking properties of coal. For example, addition of small quantities of solid or liquid chemicals to the coal or of gaseous substances to the fluidizing medium has possibilities; but the presence of such chemicals in the resulting char would render it unsuitable for metallurgical coke-making.

Byproduct Recovery. Apart from the char, the products which leave the fluidized bed consist of condensable vapours (tar, liquor and light oil) and non-condensable gases (carbonization gases plus the residue of the fluidizing medium) together with entrained char dust.

The dust cyclones are maintained at 400°C. to prevent deposition of pitch. The tar and liquor are condensed by cooling the gas stream to about 20°C. by means of a surface condenser. A portion of the condensable products forms a fog which is separated from the fixed gases by means of a cyclone separator and an electrostatic precipitator; often more than half of the tar and liquor is recovered in this way. The non-condensable gases are scrubbed with acid to remove ammonia; with alkali to remove acid gases such as H_2S, HCN, SO_2 and part of the CO_2; and, finally, with chilled wash oil to recover light oil present as vapour. The spent liquors from the acid and alkali scrubbers are analysed and the light oil is recovered from the wash oil by steam distillation.

After extraction of the condensable byproducts the purified gas is metered and then either recycled or withdrawn from the plant.

Instrumentation and Control. The instruments and controls on the experimental plant are comparatively simple, but adequate for taking all important measurements and for controlling operating conditions with a minimum of labour.

The gas flow into the plant is set manually with an orifice meter and requires no more than an occasional slight adjustment. The coal feed rate is set by the speed of rotation of the screw feeder. The total weight of coal used is measured separately. The gas output is metered continuously throughout a run and all solid and liquid products are weighed.

The carbonizing temperature is controlled as described earlier and the cumulative energy input to the bed heaters continuously indicated. The temperatures and pressures are measured at various points in the plant, the more important temperatures being registered by a multi-point temperature recorder. This instrument gives early indication of abnormal conditions occurring in the carbonizer. For example, if a stationary region develops in the fluidized bed, the temperature readings at the top, middle and bottom of the bed begin to diverge because the heat is no longer being uniformly distributed.

A two-pen differential-pressure recorder has also proved advantageous in monitoring the performance of the fluidized bed. Continuous records are obtained both of the pressure drop across the whole bed and of that across a fixed height of the bed. Both pens draw bands rather than single lines, thereby recording the rapid fluctuations associated with fluidized beds and the mean values reveal the density and height of the bed. Steady mean values indicate good fluidization and uniform processing throughout the run.

EFFECTS OF OPERATING VARIABLES

Experimental work with Wallarah seam coal has been described more fully elsewhere[23]; some of the results are shown in Table 4 and Figs. 4 and 5. The main findings may be summarized under three headings, namely carbonizing temperature, particle residence time, and type of fluidizing gas.

Carbonizing Temperature. Table 4 shows that when air is used as fluidizing medium, char yield decreases with temperature, while the yields of tar, liquor, and gas increase. The fall in the volatile-matter content of the char indicates greater degree of carbonization obtained at high temperatures, while the decrease in bulk density is due to the increased swelling of the particles caused by the faster rate of carbonization. The increase in ash yield of the char with temperature is due partly to increased carbonization and partly to increased combustion.

Particle Residence Time. Some of the particles which enter a well-mixed fluidized bed move relatively quickly to the outlet pipe while others avoid discharge almost indefinitely. Several studies of this problem of residence-time distribution have been reported, including one by the Division of Coal Research[28], but a mean residence time is sufficient for the present comparative purpose.

Fig. 4 shows that at a given carbonizing temperature the ash yield of the char rises with increasing residence time, the rate of increase being greater at the higher temperature. On the other hand, the d.a.f. volatile matter at first decreases with residence time and then levels out at an equilibrium value which depends upon the carbonizing temperature. These equilibrium values are the same for both air and recycle gas, showing that the volatile content of the char is not appreciably influenced by combustion reactions.

Yields of char and organic liquid products (tar plus scrubber naphtha) are given in Fig. 5. At 460°C. the char yield falls steadily over a range of short residence times and thereafter remains constant. There is a striking similarity between this curve and the corresponding volatile-matter curve

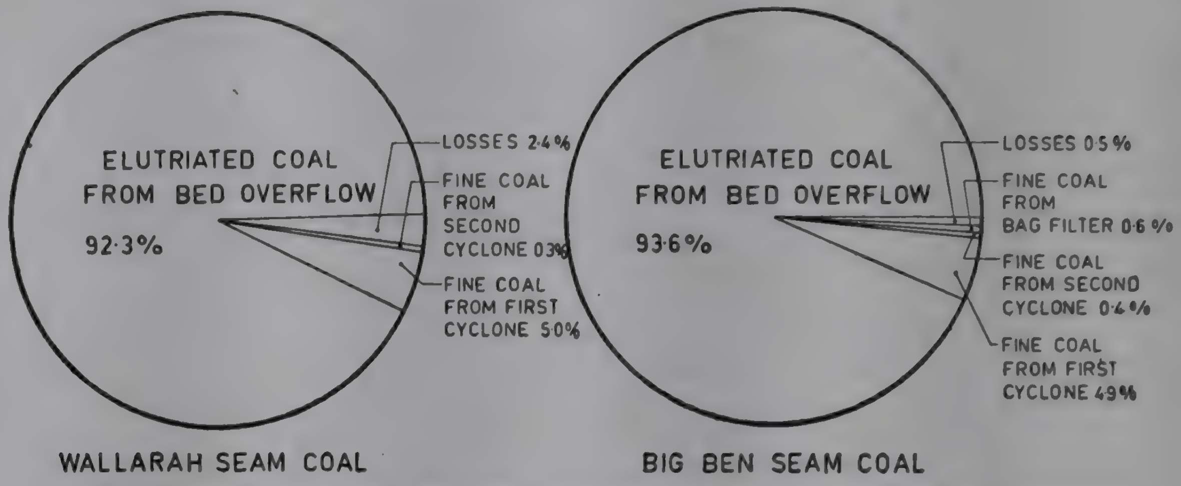

FIG. 3—TYPICAL YIELDS OF PRODUCTS OBTAINED BY ELUTRIATION OF TWO DIFFERENT NEW SOUTH WALES COALS

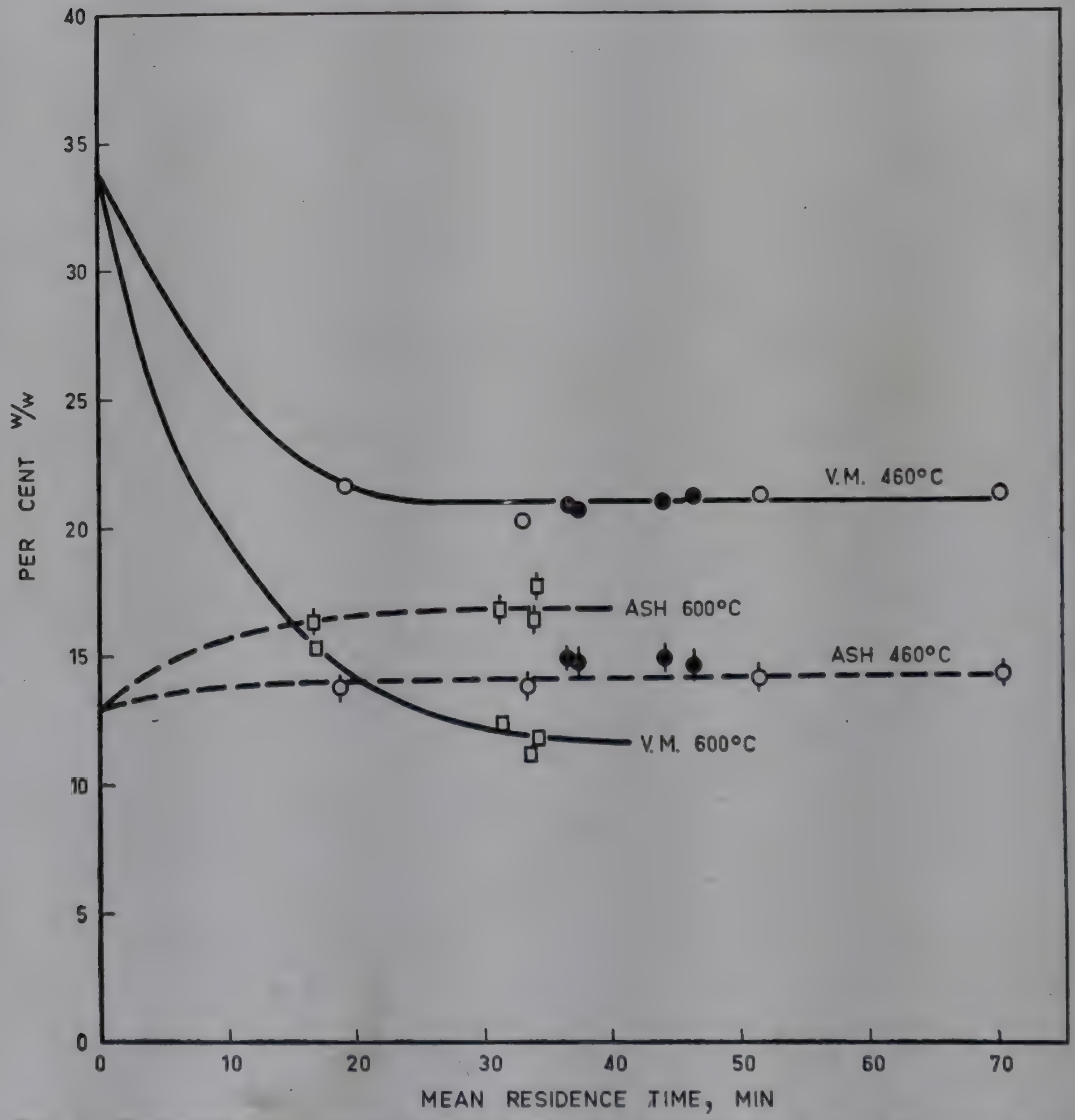

FIG. 4—INFLUENCE OF PARTICLE RESIDENCE TIME ON COMPOSITION OF CHAR. VALUES SHOWN AT ZERO RESIDENCE TIME ARE THOSE FOR THE ORIGINAL COAL (WALLARAH SEAM): ○ Volatile matter—460°C., air; ● Volatile matter—460°C., recycle gas; □ Volatile matter—600°C., air; ϕ Ash—460°C., air; ● Ash—460°C., recycle gas; ⌷ Ash—600°C., air; — Volatile matter (D.A.F. basis); --- Ash (dry basis)

TABLE 4—PILOT PLANT RESULTS AT COMPARABLE RESIDENCE TIMES, SHOWING EFFECT OF CARBONIZING TEMPERATURE—WALLARAH SEAM COAL, FLUIDIZED WITH AIR

Temperature (°C.)	460	500	550	600
Mean coal feed rate (lb./hr)	37·6	34·5	35·2	26·5
Calculated mean residence time of particles (min.)	35·0	35·1	31·2	34·3
Product yields (% w/w coal)				
(*a*) Char	84·0	80·5	76·0	71·2
(*b*) Dry tar and pitch	4·9	5·3	7·2	8·0
(*c*) Liquor	9·7	10·5	11·6	13·2
(*d*) Scrubber naphtha	0·2	0·1	0·4	0·4
(*e*) Gas (N_2-free)	8·0	8·7	10·8	15·7
(*f*) Total organic liquids (*f*) = (*b*) + (*d*)	5·2	5·4	7·7	8·4
Properties of char*				
Ash (% w/w dry basis)	13·9	15·1	15·9	16·4
Volatile matter (% w/w d.a.f.)	20·1	19·1	17·3	11·3
Bulk density (lb./cu. ft)	29·2	27·1	23·9	17·8

*For comparison, properties of feed coal were: Ash (% w/w dry basis), 13·0; Volatile matter (% w/w d.a.f.), 34·0; Bulk density (lb./cu. ft), 48·0.

in Fig. 4, both showing that at 460°C. there is no further change in the char after carbonization is complete. At 600°C. the effect of carbonization can be seen from the early part of the char-yield curve in Fig. 5, but instead of levelling out to an equilibrium value after carbonization is complete this curve shows a progressive loss of char with time, due to combustion.

With recycle gas as the fluidizing medium, the yield of organic liquid products is approximately the same at all temperatures within the range 460°-600°C. The same yield is obtained when using air at 600°C. but only about half this amount with air at 460°C. It is concluded that losses of tar and naphtha are negligible at 600°C. but that in the presence of air extensive combustion of these products occurs at 460°C. The significance of these results in choosing desirable conditions for plant operations has been already discussed.

Type of Fluidizing Gas. Fewer runs have been carried out with recycle gas than with air, but the trends in ash and d.a.f. volatile-matter contents are similar for char prepared with either of these fluidizing gases. The main difference is not in the composition but in the yields of the products.

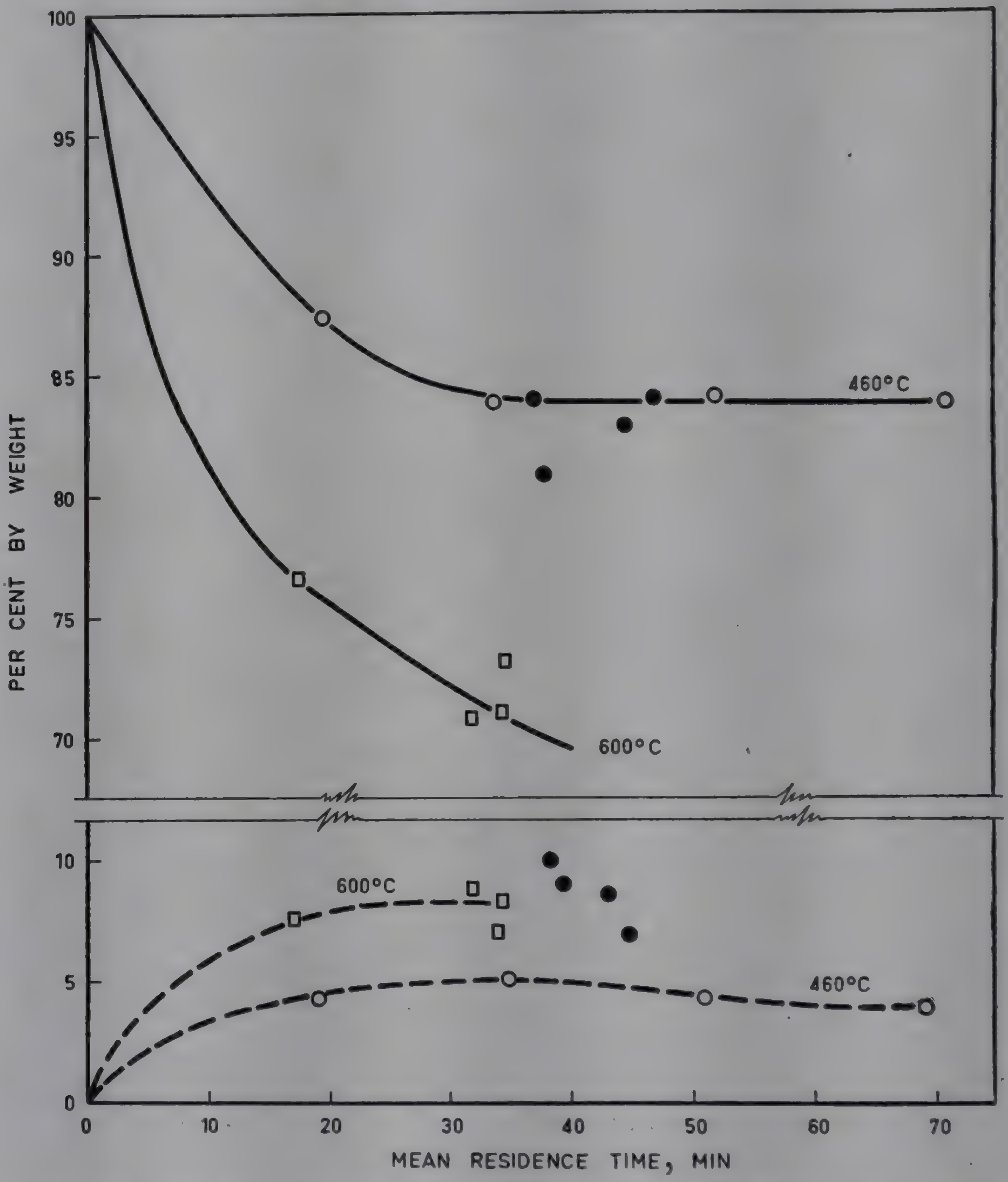

Fig. 5—Influence of particle residence time on yields of char and organic liquid products (Wallarah seam): ○ 460°C. using air; ● 460°C. using recycle gas; ☐ 600°C. using air; — Char; --- Organic liquid products

GENERAL CONCLUSIONS AND FUTURE PROSPECTS

While the application of fluidization to l.t.c. offers advantages it is subject to several operating difficulties. These may, however, be overcome by appropriate design and operating techniques, so that from a technical viewpoint the process appears to be suitable for large-scale operation.

However, there are still economic obstacles to commercial development, mainly because satisfactory markets have not yet been found for the tar and its derivatives. Until this problem is solved, the best prospects for l.t.c. appear to lie in the production of char for special purposes such as the manufacture of metallurgical coke and smokeless fuel, where local conditions justify the processing cost involved.

In the meantime, certain technical possibilities merit further attention, among them the use of multi-stage fluidized-beds to achieve more uniform residence times and greater control of the carbonization process. Developments along these lines may also help to improve the overall economics of fluidized-bed carbonization.

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Study of Coal Carbonization in the Fluidized State : II

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The nominal residence time of the fluid reactants taken conventionally as basis for predicting performance of fluid-bed reactors alone is inadequate for the scaling-up operations, when solid materials are undergoing reactions in fluid-bed, e.g. carbonization of coal in fluidized bed. An attempt is made to study the effect of certain operating variables like bed temperature and mass velocity of fluid on the rate of devolatilization of coal in a dense-fluidized bed, operated continuously, and to correlate the nominal residence time with the actual residence time of particles in the carbonizer.

The performance of a reactor with respect to the yield and product distribution is greatly influenced by the residence time of materials, and its importance in reactor design is well recognized. The nominal residence time (N.R.T.) during which all portions of the feed will reside in the reactor is taken usually as basis for design purposes. Difficulty arises, however, in actual plant operations where there is a 'spread' or 'distribution' of residence time for the various fractions of the material. Correlations to find out the same are reported in literature for stirred-tank reactors[1–8] for homogeneous as well as heterogeneous reactions and for reactors in which the gaseous materials are subjected to some sort of transformation in the presence of catalysts[9–25]. The leading contributions in this field dealing with solid reactant are those of Kilinkenberg[26,27], Levenspiel and Smith[28], Kirillov[29,30], Tiller[31], Kalbach[32,33], Parent *et al.*[34], and Kasten and Amundson[35]. Probability type of equations have been offered by Parent *et al.* and by Kasten and Amundson, the latter having dealt with reactions in flow-type of reactors.

In the present work, an attempt has been made to find out experimentally the effect of certain operating variables like gas mass velocity and bed temperature on the rate of devolatilization and the average residence time (A.R.T.) of the particles in a fluidized carbonizer. A comparison of the A.R.T. with the N.R.T. is presented.

EXPERIMENTAL

The apparatus described earlier[36] consists of a 2·25 in. i.d. fluidizer fitted with a 0·625 in. o.d. cylindrical baffle of 3 ft height, fixed concentrically. External electrical heating provides the heat requirement.

Experiments were carried out with noncoking coal of different mesh sizes with a volatile matter of 23·5 per cent and ash 28·9 per cent (dry basis). The fluidizing mass velocities of air were 844 and 1042 lb./hr/sq. ft respectively. Different bed temperatures in the range of 775-1165°F. and solid feed rates 14·95-64·15 lb./hr were used. The operation was continuous.

The reactor was heated with continuous supply of air and when the desired temperature was reached coal was fed continuously by means of a screw-feeder. Heat input was regulated to maintain a uniform bed temperature. When steady state was attained, representative char sample was taken for analysis. The feed rate was measured and the bed density determined by trapping the solids retained in the fluidizers.

RESULTS AND DISCUSSION

The operating conditions and the analysis of char are given in Table 1. As the temperature of the bed was increased, rate of loss of volatile matter

TABLE 1—DENSE BED CONTINUOUS CARBONIZATION
[2·25 in. i.d. fluidizer with 0·625 in. o.d. baffle; D_p, 0·001969 ft;
Feed size, —22 +30 mesh (B.S.S.)]

RUN NO.	AIR MASS VELOCITY lb./hr/sq.ft	AV. BED TEMP., °F.	SOLID FEED RATE g./min.	SOLID TRAPPED g.	CHAR ANALYSIS (dry basis) V.M., %	ASH, %	V.M. REMOVED %
1	844	815	323	445	16·67	35·24	41·76
2	,,	895	485	615	16·02	36·87	46·46
3	,,	930	240	350	15·55	37·44	48·87
4	,,	995	352	502	14·46	38·37	53·59
5	,,	1165	113	190	11·68	43·59	67·25
6	1042	775	355	425	18·42	34·70	34·63
7	,,	825	470	635	17·59	35·38	39·51
8	,,	840	254	386	16·27	36·15	44·58
9	,,	925	189	350	13·16	38·37	57·97
10	,,	1060	176	310	7·39	37·88	54·33

also increased, when the mass velocity of air was kept the same. But considering the effect of mass velocity at constant bed temperature, it was observed that the extent of devolatilization did not always increase (except in one case) with increase in mass velocity. By increasing mass velocity, the residence time of particles inside the reactor decreased, i.e. degassing is likely to be less; at the same time, as it has been shown earlier[36], increase in mass velocity results in an increase in devolatilization (due to oxidation, etc.). These two opposing factors act simultaneously and from the present

TABLE 2—PROPERTIES OF CHAR OBTAINED FROM FLUIDIZED CARBONIZATION

[Feed size: —22 +30 mesh (B.S.S.)]

RUN NO.	BED TEMP. °F.	SIEVE ANALYSIS	QTY. WT %	V.M. (dry basis) %	ASH (dry basis) %	V.M. (moisture and ash-free basis) %
1*	815	+16	1·15	17·40	34·60	26·60
		—16 +22	28·74	17·00	39·95	28·30
		—22 +30	57·48	16·50	38·90	27·00
		—30	12·63	16·50	36·30	25·50
3*	930	+16	19·18	14·66	34·68	22·44
		—16 +22	34·25	14·86	35·54	23·05
		—22 +30	38·35	15·82	37·50	25·33
		—30	8·22	15·92	35·87	24·84
4*	995	+16	3·33	15·97	34·71	24·46
		—16 +22	37·79	14·63	39·44	24·16
		—22 +30	50·00	14·18	38·15	22·95
		—30	8·88	14·67	58·53	23·88
5*	1165	+16	23·80	9·79	43·75	17·40
		—16 +22	23·71	9·92	43·69	17·63
		—22 +30	37·66	10·85	42·85	18·98
		—30	14·83	11·98	41·05	20·31
6**	775	+16	0·89	17·60	36·76	27·82
		—16 +22	23·21	17·62	39·02	28·89
		—22 +30	62·50	18·74	36·84	29·66
		—30	13·40	18·29	33·45	27·49
8**	840	+16	3·77	16·17	32·65	24·01
		—16 +22	28·30	15·39	36·50	24·25
		—22 +30	56·60	16·54	36·56	26·04
		—30	11·33	16·71	33·82	25·26
7**	825	+16	1·00	17·19	40·00	28·83
		—16 +22	33·00	17·65	40·66	29·75
		—22 +30	49·00	17·25	39·80	28·64
		—30	17·00	17·28	33·36	25·96
9**	925	+16	4·63	13·70	30·28	19·60
		—16 +22	40·75	10·40	37·38	16·60
		—22 +30	42·60	15·10	40·78	25·60
		—30	12·02	15·30	37·70	25·40

*Air mass velocity: 844 lb./hr/sq.ft; **Air mass velocity: 1042 lb./hr/sq. ft.

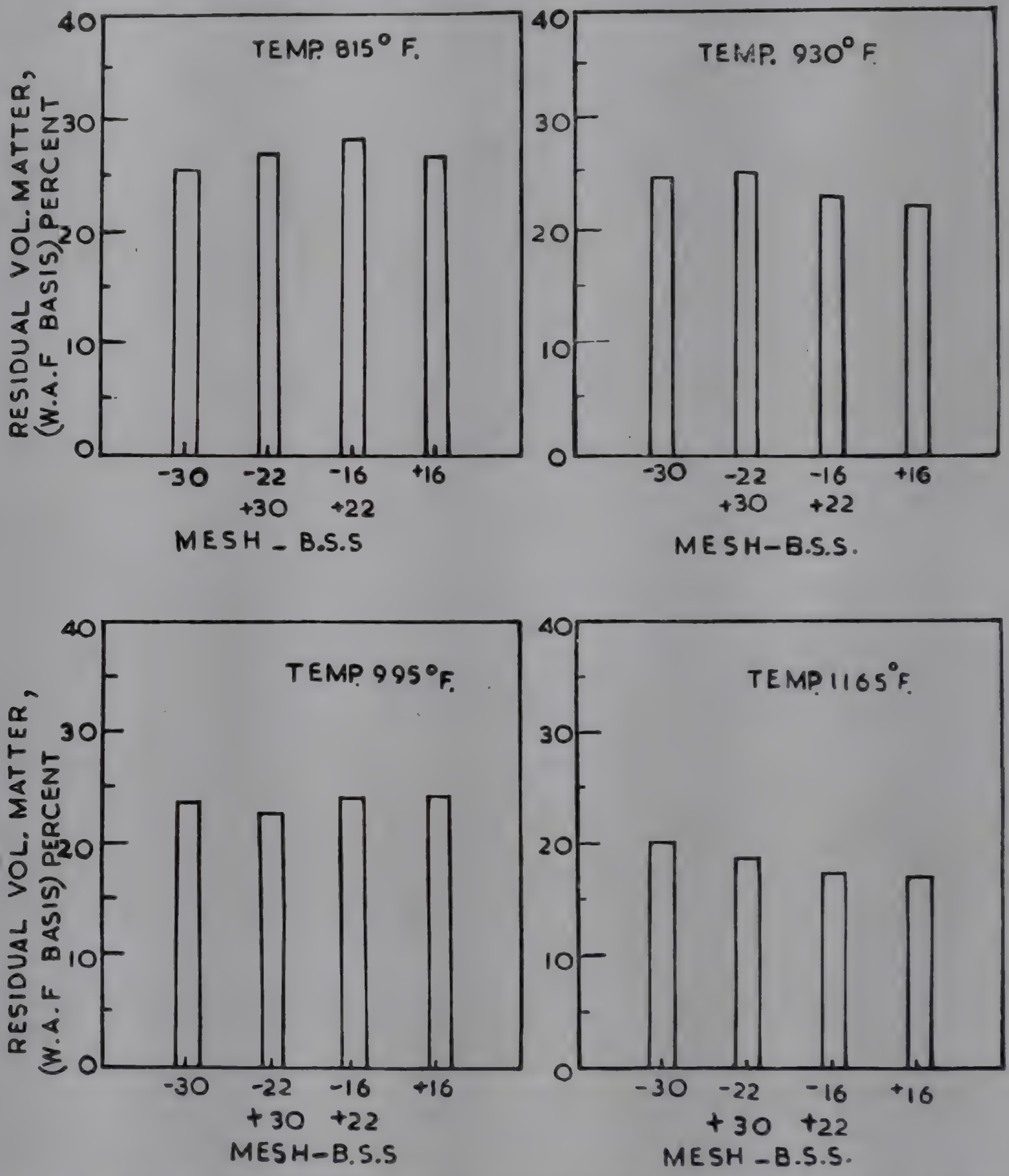

FIG. 1—DENSE BED CONTINUOUS CARBONIZATION—ANALYSIS OF CHAR (CYCLONE). AIR MASS VELOCITY — 844 lb./hr/sq.ft

data it is difficult to arrive at a definite conclusion as to which of the effects is more predominant.

In continuous carbonization, it is possible that some particles may stay inside the reactor for a longer period than others. The degree of devolatilization and the extent of carbonization will be different in these cases. To investigate this the char particles were sieved into different size fractions and the residual volatile matter content of the fractions were determined. The results are given in Table 2.

Figs. 1 and 2 show the distributions of residual volatile matter content (calculated on moisture and ash-free basis) in the various size fractions.

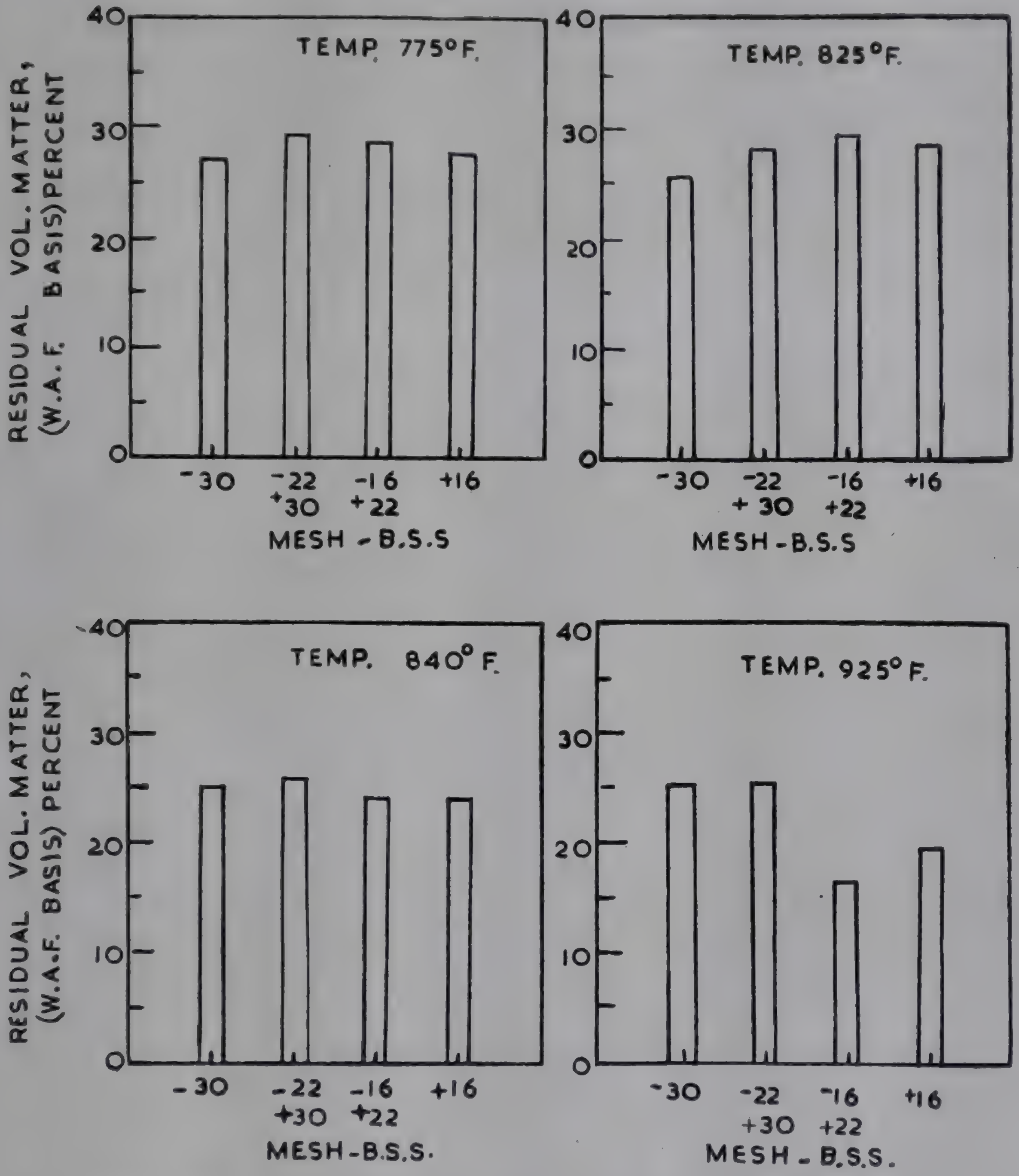

Fig. 2—Dense bed continuous carbonization—analysis of char (cyclone). Air mass velocity — 1042 lb./hr/sq.ft

The variation is usually very small and no definite trend is observed and as such it is not possible to ascertain the relative distribution of residence time for various fractions of the product. However, in general, the bigger char particles have lesser ash content than the finer fractions. It has been observed by earlier workers[37] that the strongly coking fractions of coal like vitrain, clarain, etc. have lower ash content. It is, therefore, expected that the low ash fractions will be more swelling (evident from the increase in size) after carbonization.

In Table 3 the results obtained for the continuous carbonization studies have been compared by taking sets of data nearly in the same range of bed

TABLE 3—DENSE BED CONTINUOUS FLUIDIZED CARBONIZATION

(Comparison of nominal and average residence time)

Run No.	Air mass velocity	Average bed temp. °F.	Solid feed rate g./min.	Solid trapped g.	V.M. removed %	N.R.T. min.	A.R.T. min.
1	844	815	383	445	41·76	1·16	3·75
8	1042	825	470	635	39·51	1·35	3·50
7	1042	840	254	386	44·58	1·52	4·00
3	844	930	240	350	48·87	1·46	2·80
9	1042	925	189	350	57·97	1·85	2·30
5	844	1165	113	190	67·25	1·68	1·75
10	1042	1060	176	310	54·33	1·76	2·00

temperature but at different gas mass velocity. In these calculations, the N.R.T. is calculated by dividing the solids trapped in the fluidizer with the solid feed rate; whereas the A.R.T. is found out by referring to the data of batch carbonization studies[36] (obtained in the same reactor under identical conditions) and then extrapolating the same for the present data. It can be seen that there is considerable difference between the N.R.T. and A.R.T. values, the difference tending to narrow down as the temperature rises. This can be expected because degassing is a two-stage process and because of the exponential nature of the plot representing volatile matter loss against time. The A.R.T. values are always higher than those of N.R.T. which can be explained as due to the fact that in continuous fluidization the sample is withdrawn after allowing sufficient time to attain steady state conditions and as such even on the average basis the coal particles experience devolatilization to a greater extent due to the longer period of residence in the reactor.

ASSUMPTIONS

(*i*) Coal was assumed to be homogeneous in nature in so far as the chemical composition of the gross sample was concerned.

(*ii*) Extrapolation of the conditions in batch data to the present case was assumed to be valid within a reasonable accuracy.

ACKNOWLEDGEMENT

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Low Temperature Carbonization of Briquettes

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Two kinds of briquettes made from non-caking coal, anthracite, pitch and coal tar were carbonized in a furnace at constant temperature to study the basic principles of low temperature carbonization. From the decrease in weight of briquettes, the calculated overall specific heat of the briquettes was found to be 0·66-1·94 in one case and 0·82-1·07 for the other. These values were used to calculate the heat of carbonization. From the rate of decrease in the weight of briquettes, low temperature carbonization was regarded as a first order reaction and the reaction rate coefficients were calculated.

Initially, the purpose of low temperature carbonization (l.t.c.) of coal or briquettes in Japan was to get a domestic fuel of low volatile matter. Before the Second World War, studies were made from the point of view of a self-supporting liquid fuel industry, but subsequently semi-coke has been used in iron industry for blending with high volatile coal for the production of metallurgical coke.

Earlier, the results of high temperature carbonization of briquettes were reported with regard to the overall specific heat and the heat of carbonization for use in design and operation of high temperature carbonization furnace[1].

In this paper a briquette in the form of sphere was carbonized at low temperature and the overall specific heat derived from the equation and velocity of carbonization were determined for obtaining fundamental data regarding l.t.c.

APPARATUS AND EXPERIMENT

Fig. 1 shows a schematic view of the apparatus. The furnace was heated with SiC-, and Ni-Cr-heater and nitrogen gas was passed into it from the bottom to regulate the temperature at the points A, B, C and D to be same as the temperature of inner wall (T_W) of furnace. The variation in temperature was 1-2 per cent.

The sample was prepared as in Fig. 2 and attached to a balance at the point 'a' and measurements made. The mercury bottle conveys the electromotive force of thermo-couple to automatic temperature recorder without in any way being affected by up-and-down motion of the sample. Thus the decrease in weight of the briquette and the change of temperatures at each point of the briquette were recorded. The briquettes used in these experiments were prepared by mixing non-caking coal, pitch coke, anthracite and coal tar pitch at 200°C. and 150 kg./sq. cm. pressure.

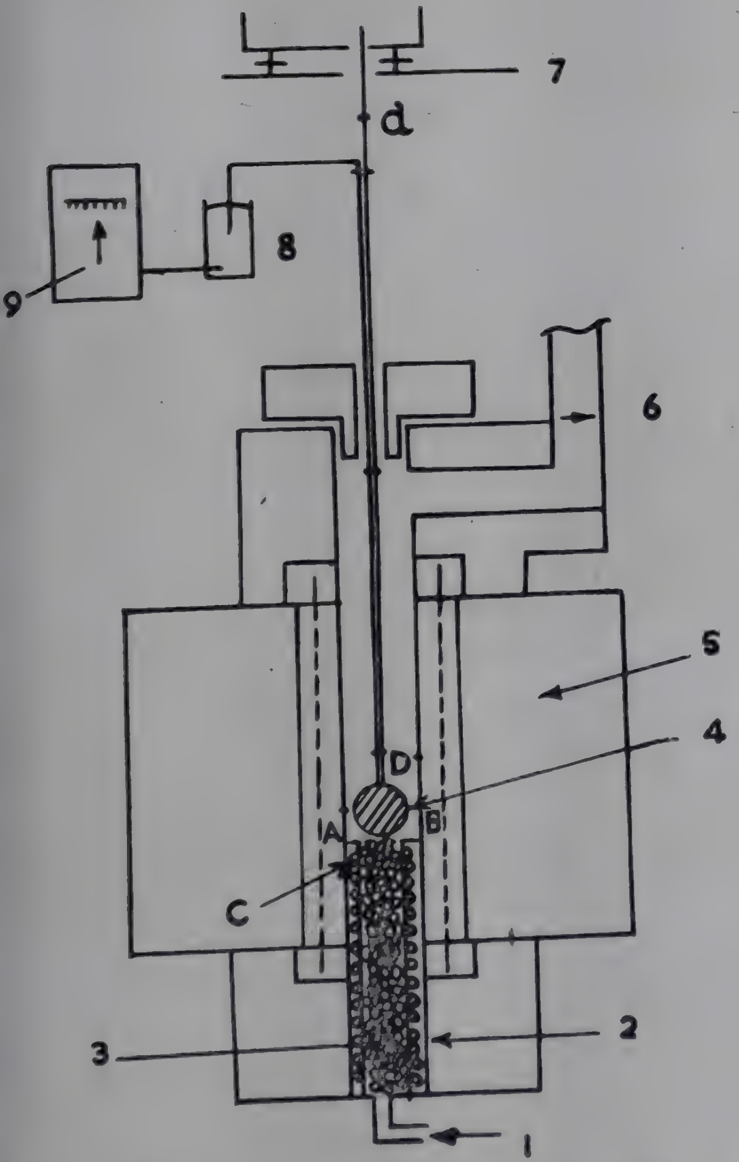

FIG. 1—SCHEMATIC VIEW OF APPARATUS: (1) Nitrogen gas (2) Nitrogen gas preheater (3) Fire brick chip (4) Sample (5) Sic furnace (6) Chimney damper (7) Balance (8) Mercury bottle (9) Automatic temperature recorder

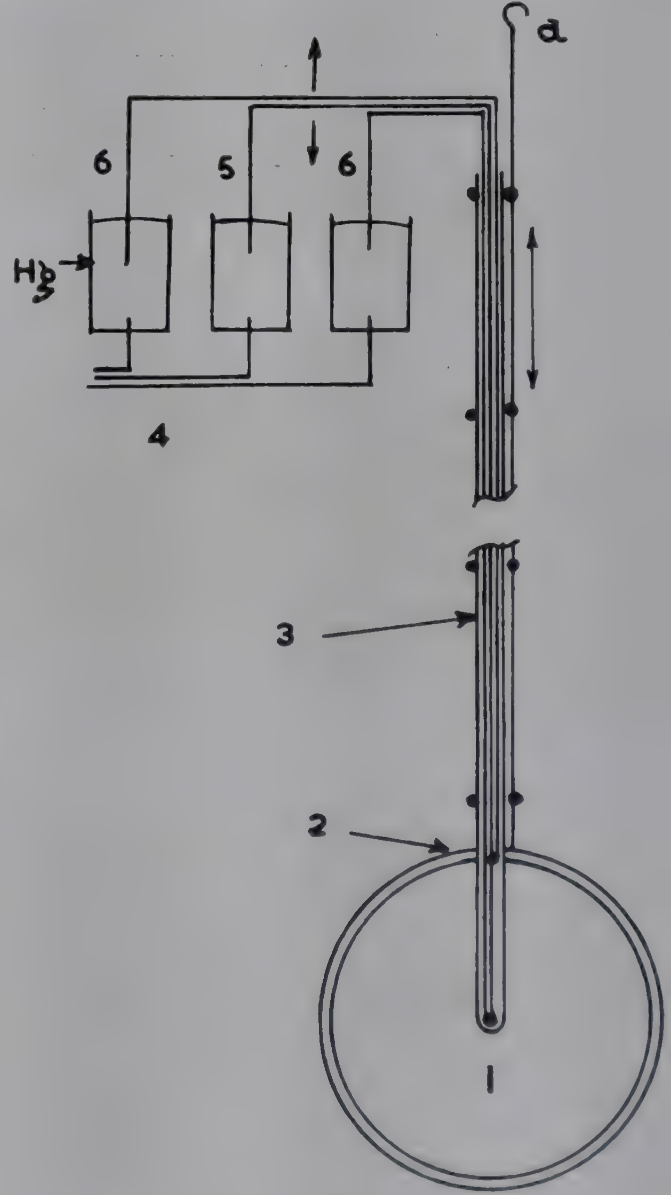

FIG. 2—SAMPLE HOLDER: (1) Sample (2) Sampl holder (3) Ceramic pipe (4) Chimney damper t automatic temperature recorder (5) Chrome (6) Alumel

TABLE 1—PROXIMATE ANALYSIS OF BRIQUETTES

	Briquette A	Briquette B
Moisture, %	2·0	2·0
Volatile matter, %	19·0	13·7
Ash, %	5·5	6·5
Fixed carbon, %	73·5	77·8

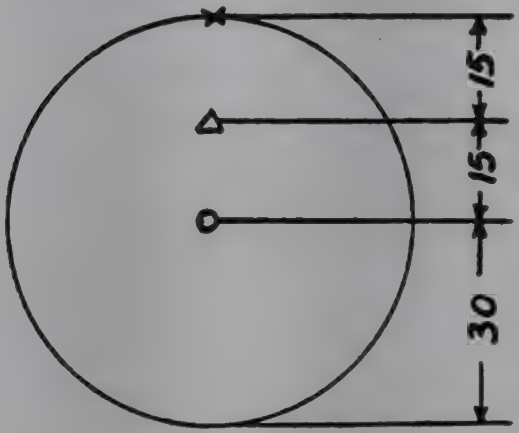

Fig. 3—Measuring points of sample (diam. 60 mm.)

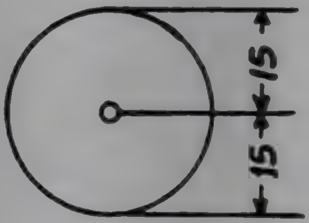

Fig. 4—Measuring points of sample (diam. 30 mm.)

The volatile matter of the briquettes was 19·0 and 13·7 per cent and the diameters 60 and 30 mm. The temperature of inner wall of furnace (T_W) tried were 650, 550 and 450°C. The proximate analysis of briquettes is given in Table 1.

RESULTS

Figs. 3 and 4 show the points in the sample where temperature was observed and these points are marked o, △, x.

Figs. 5-16 show the relationship between time and temperature which was recorded on the automatic temperature recorder.

The carbonization of briquette was stopped when the temperatures of two or three measuring points were found to be same.

DERIVATION OF EQUATION

At unsteady state of heat transfer, the fundamental equation is shown as follows:

$$\bar{C}_p \rho \frac{\delta T}{\delta t} = \lambda \left(\frac{\delta^2 T}{\delta r^2} + \frac{2}{r} \cdot \frac{\delta T}{\delta r} \right) \tag{1}$$

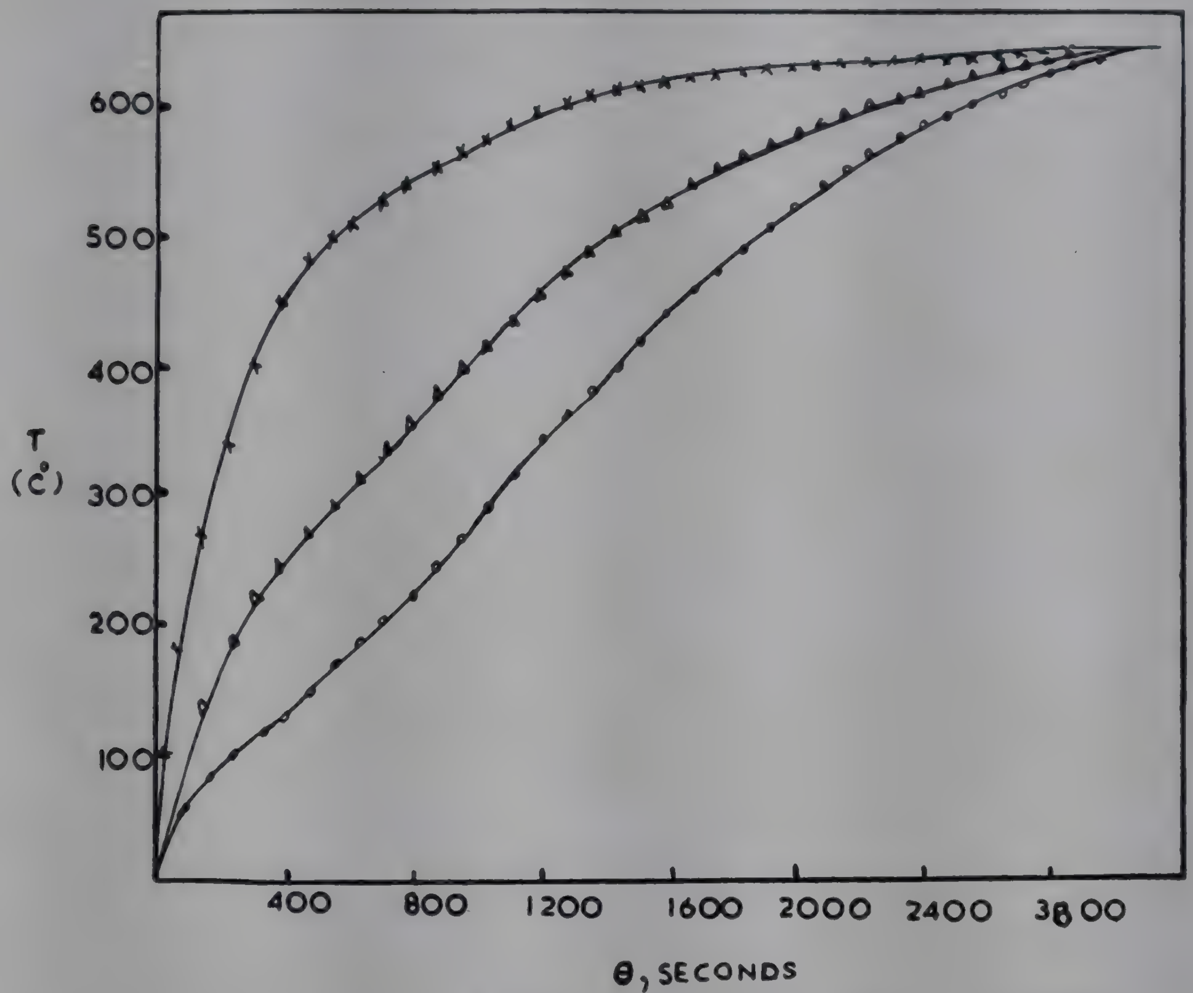

Fig. 5—T vs θ for briquette A: Volatile matter 19%; diam. 60 mm.; T_w 650°C.

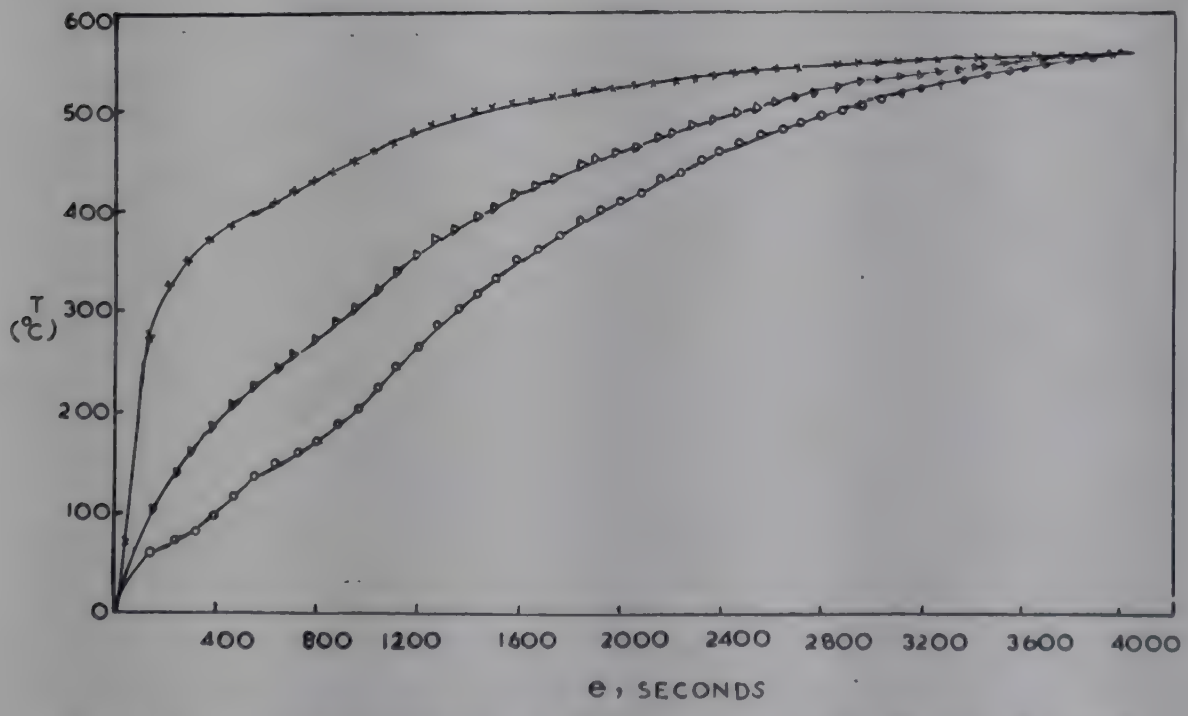

Fig. 6—T vs θ for briquette A: Volatile matter 19%; diam. 60 mm.; T_w 550°C.

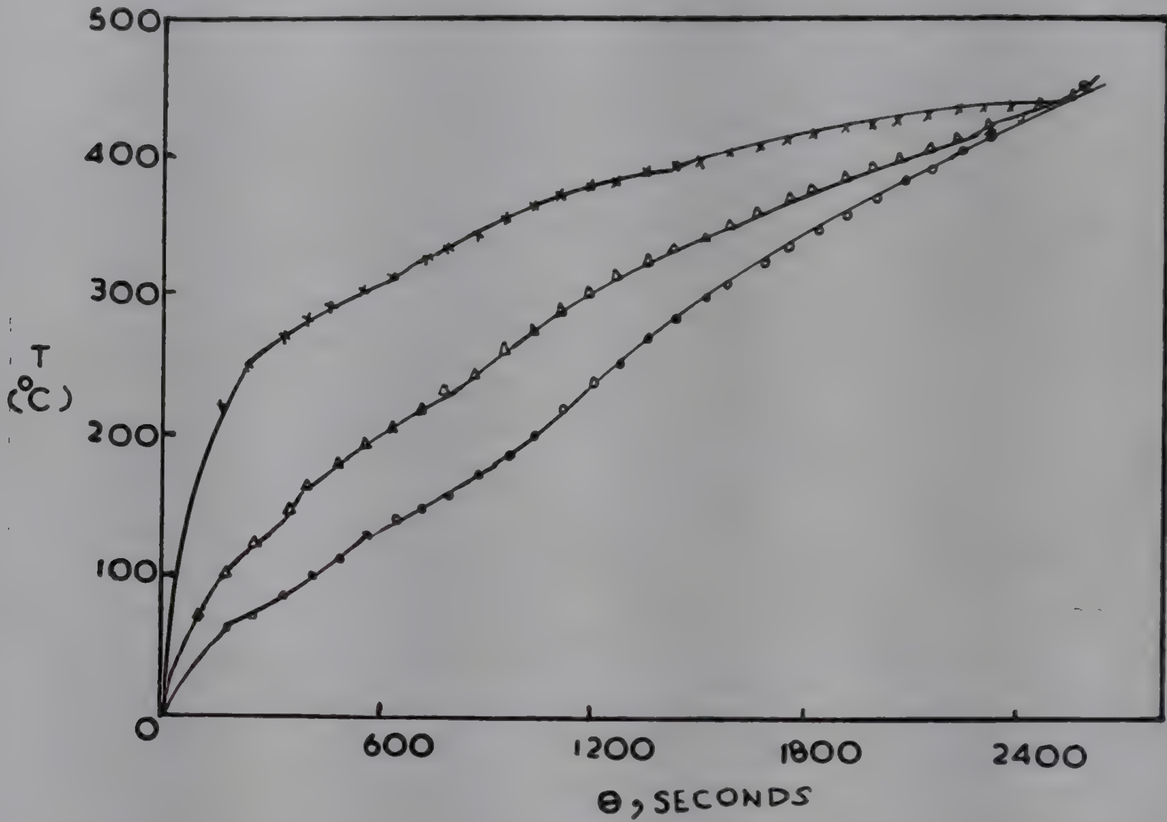

FIG. 7—T vs θ FOR BRIQUETTE A: Volatile matter 19%; diam. 60 mm.; T_w 450°C.

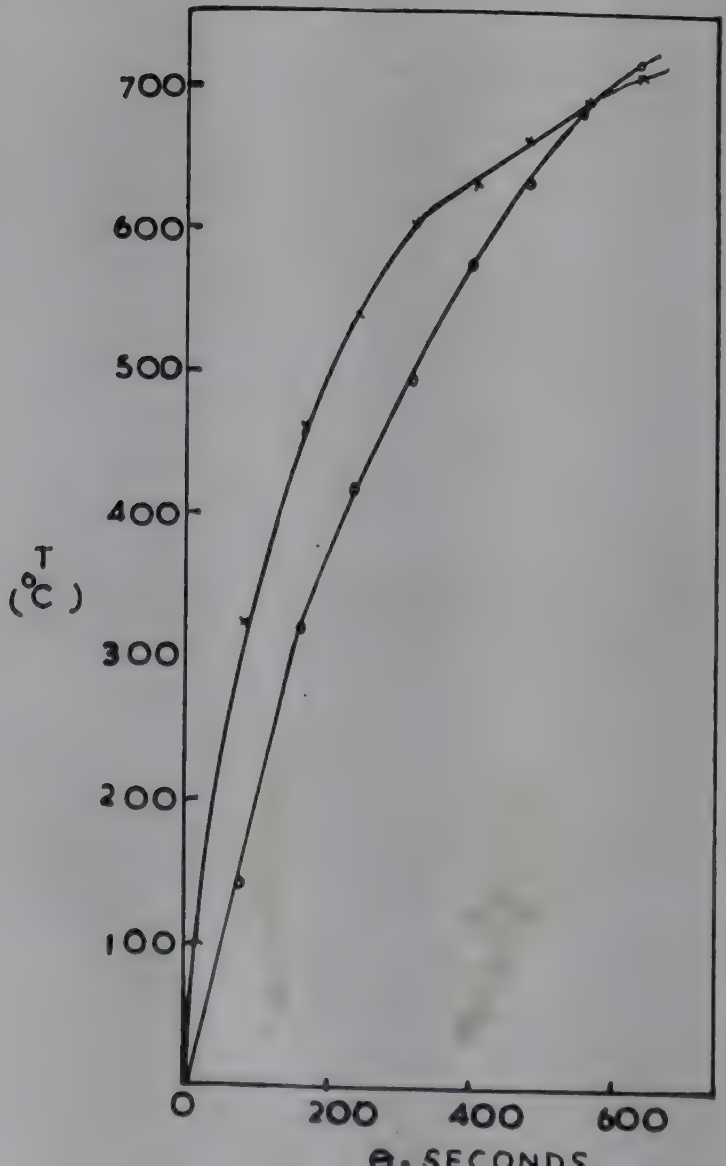

FIG. 8—T vs θ FOR BRIQUETTE A: Volatile matter 19%; diam. 30 mm.; T_w 650°C.

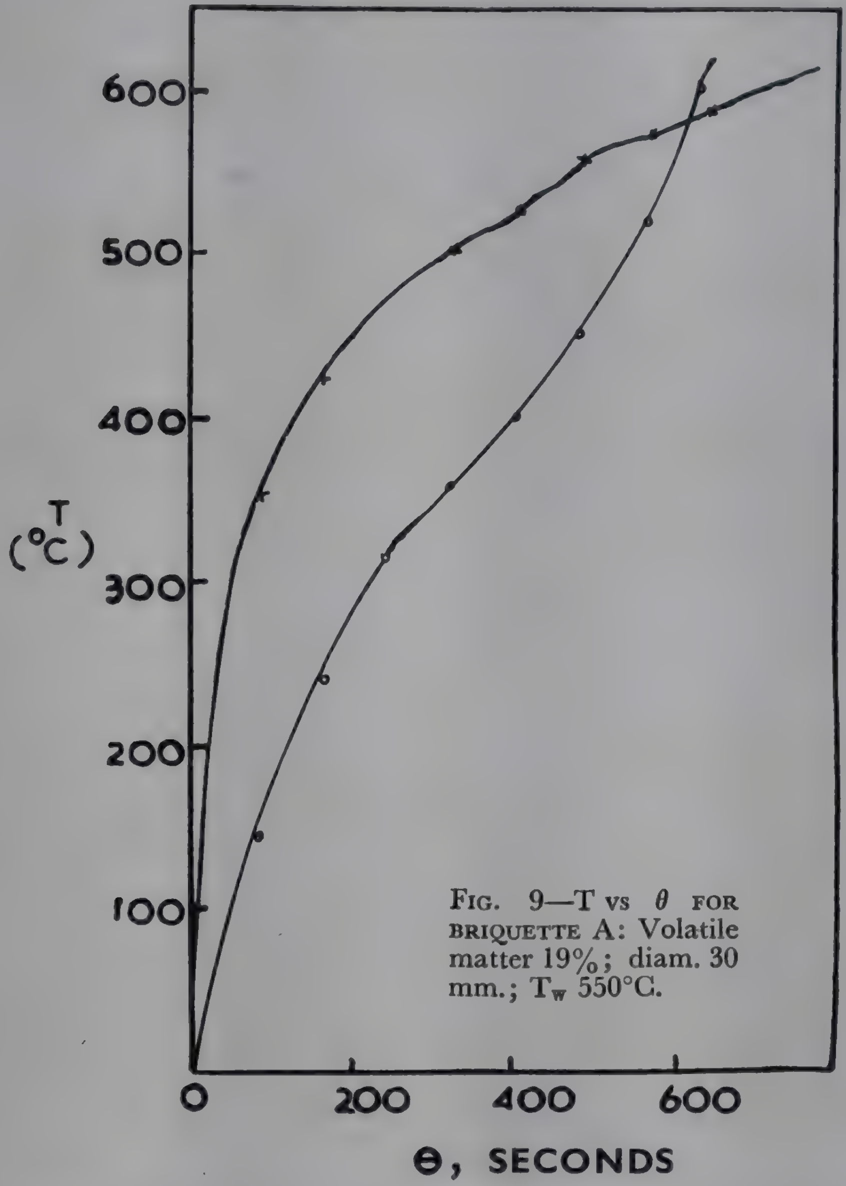

Fig. 9—T vs θ for briquette A: Volatile matter 19%; diam. 30 mm.; T_w 550°C.

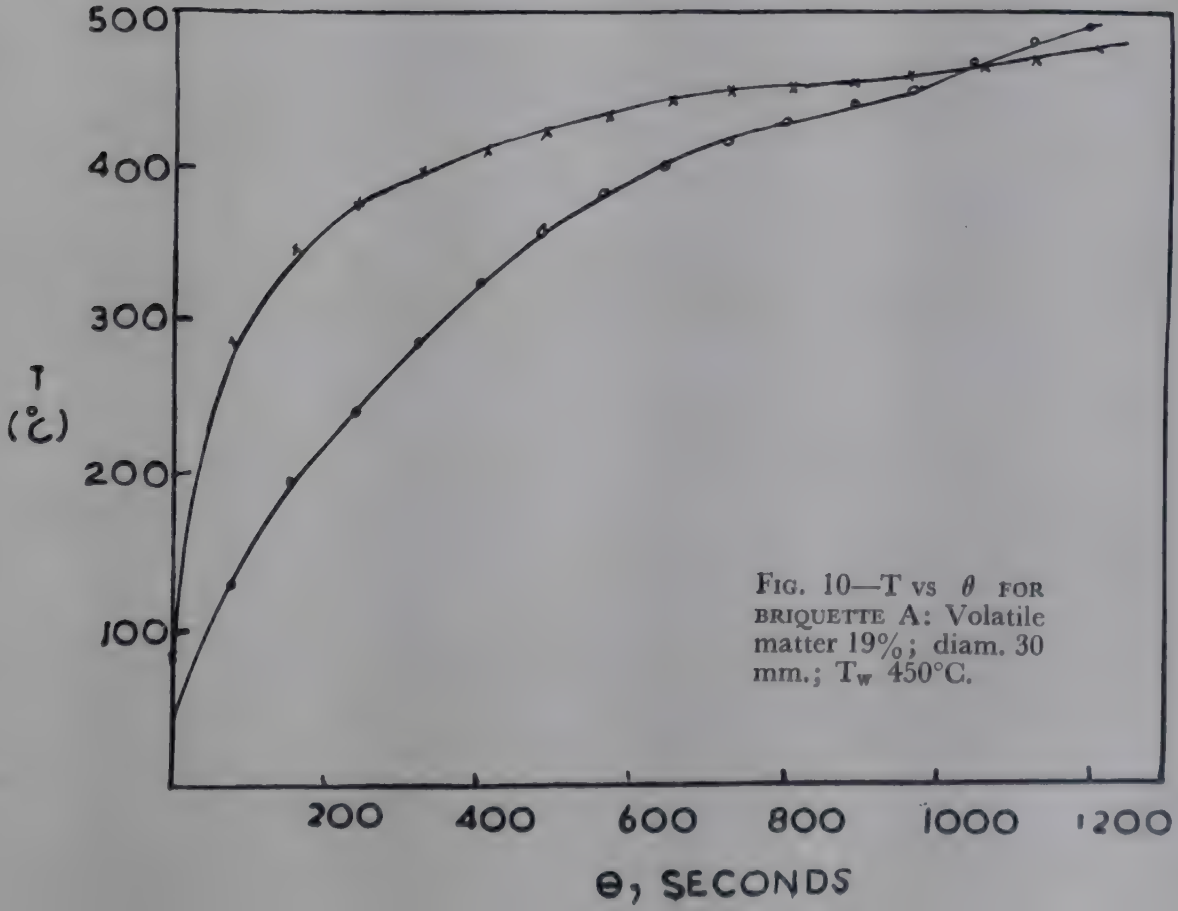

Fig. 10—T vs θ for briquette A: Volatile matter 19%; diam. 30 mm.; T_w 450°C.

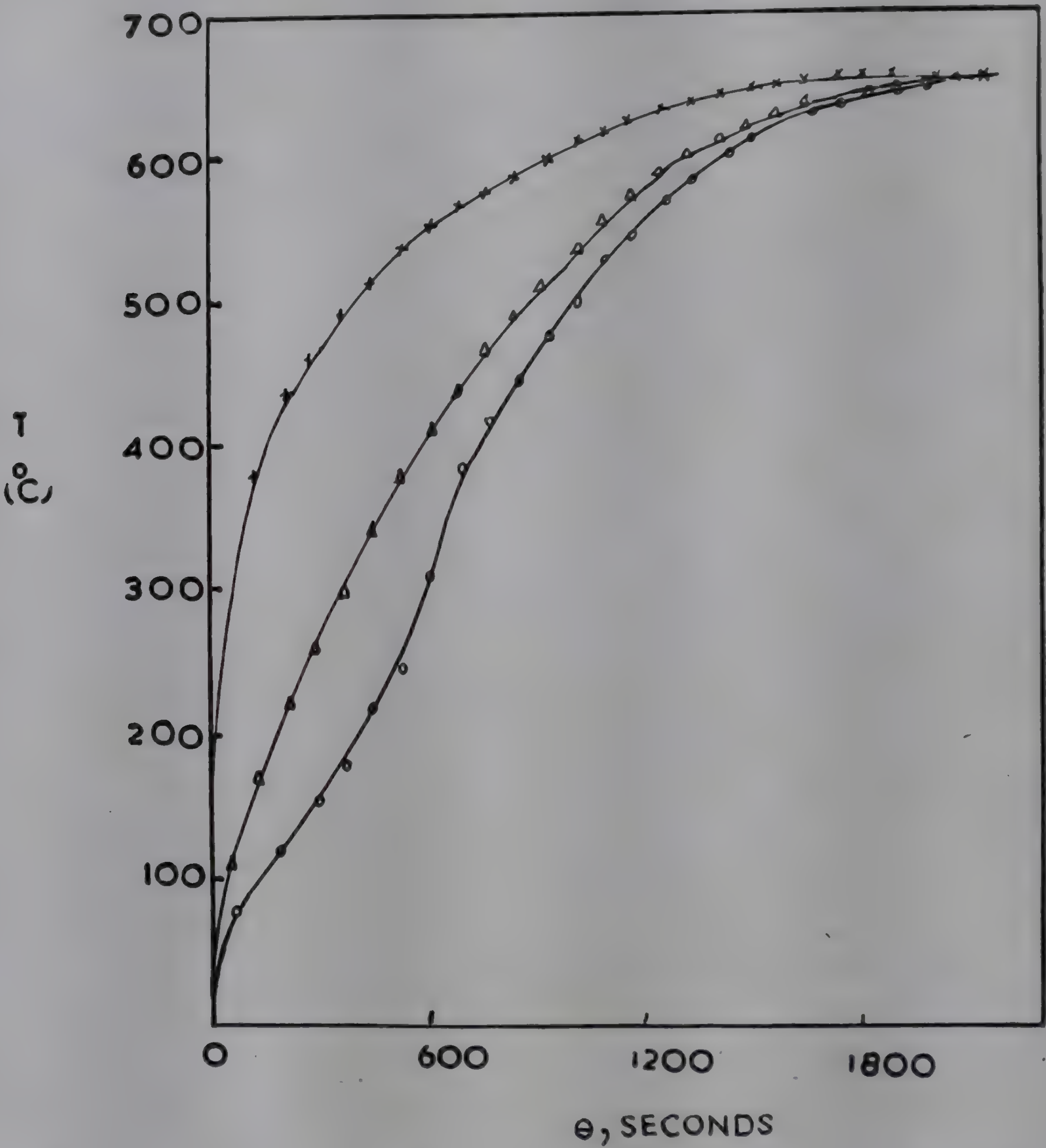

FIG. 11—T vs θ FOR BRIQUETTE B: Volatile matter 13·7%; diam. 60 mm.; T_w 650°C.

ρ, $\bar{C}_p$, λ are represented as the functions of temperature and written as

$$\bar{C}_p = \bar{C}_p\,(T),\ \lambda = \lambda\,(T) \tag{2}$$

$a(m)$ shows the radii of a sphere and the length from the centre to radius direction's point is shown as $r(m)$, and now assume the temperature distribution on the co-ordinate system as given by the following equation:

$$T = T_o + (T_1 - T_o)\left(\frac{r}{a}\right)^2 \tag{3}$$

T_o, T_1 are temperatures at $r=0$, $r=a$. This equation is differentiated with respect to r as

$$\frac{\delta\,T}{\delta\,r} = \frac{2}{a^2}\,(T_1 - T_0)\,r \tag{4}$$

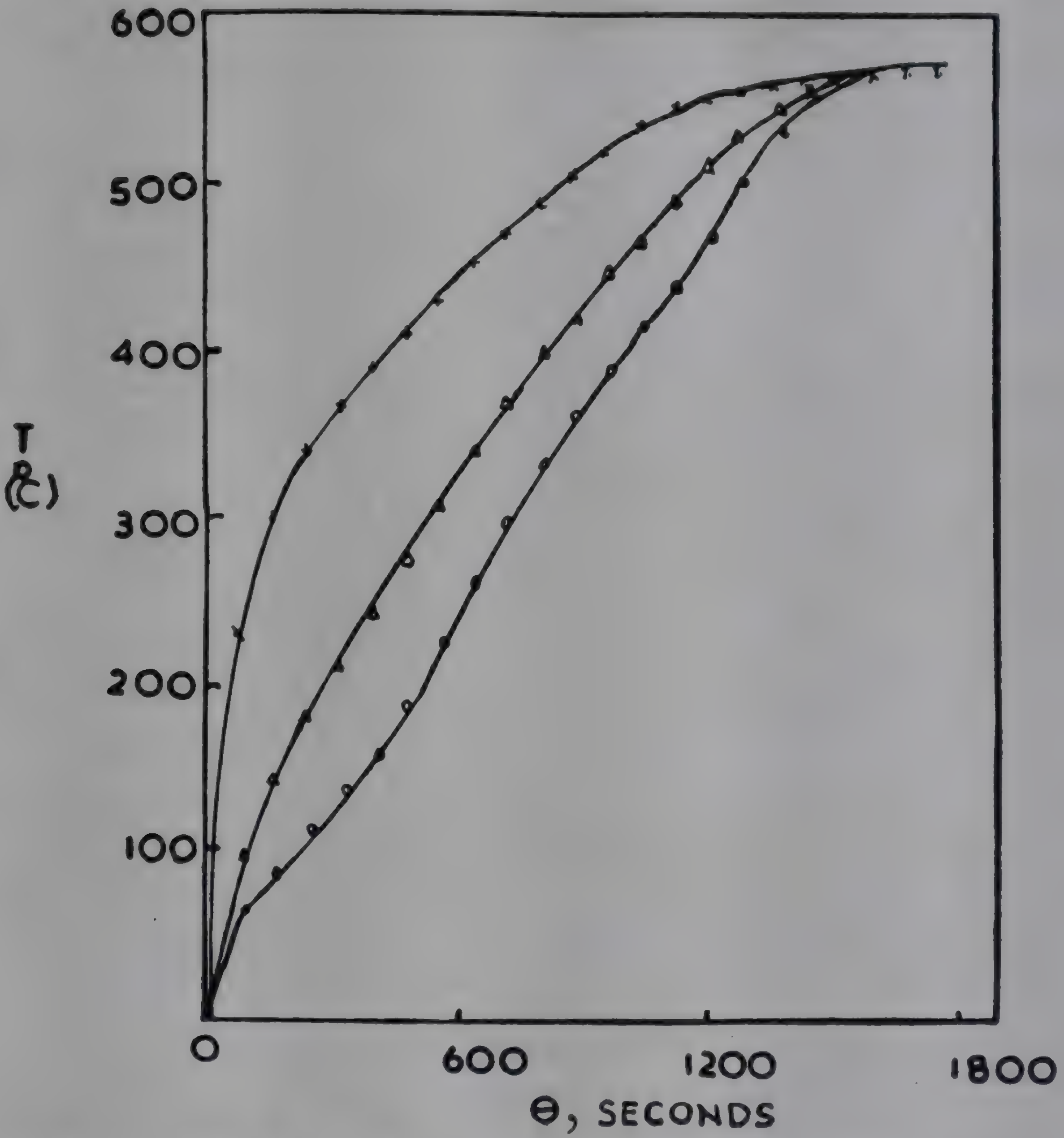

FIG. 12—T vs θ FOR BRIQUETTE B: Volatile matter 13·7%; diam. 60 mm.; T_w 550°C.

$$\frac{\delta^2 T}{\delta r^2} = -\frac{2}{a^2}(T_1 - T_0) \tag{5}$$

(2), (4), (5) are substituted in (1) and transformed as follows:

$$\frac{\bar{C}_p(T)}{\lambda(T)} \cdot \frac{\delta T}{\delta t} = \frac{6}{\rho a^2}(T_1 - T_0) \tag{6}$$

$$= \beta(T_1 - T_0) \tag{7}$$

$$\text{where } \beta = \frac{6}{\rho a^2}$$

Equation (7) multiplied by δt and integrated makes the equation (8)

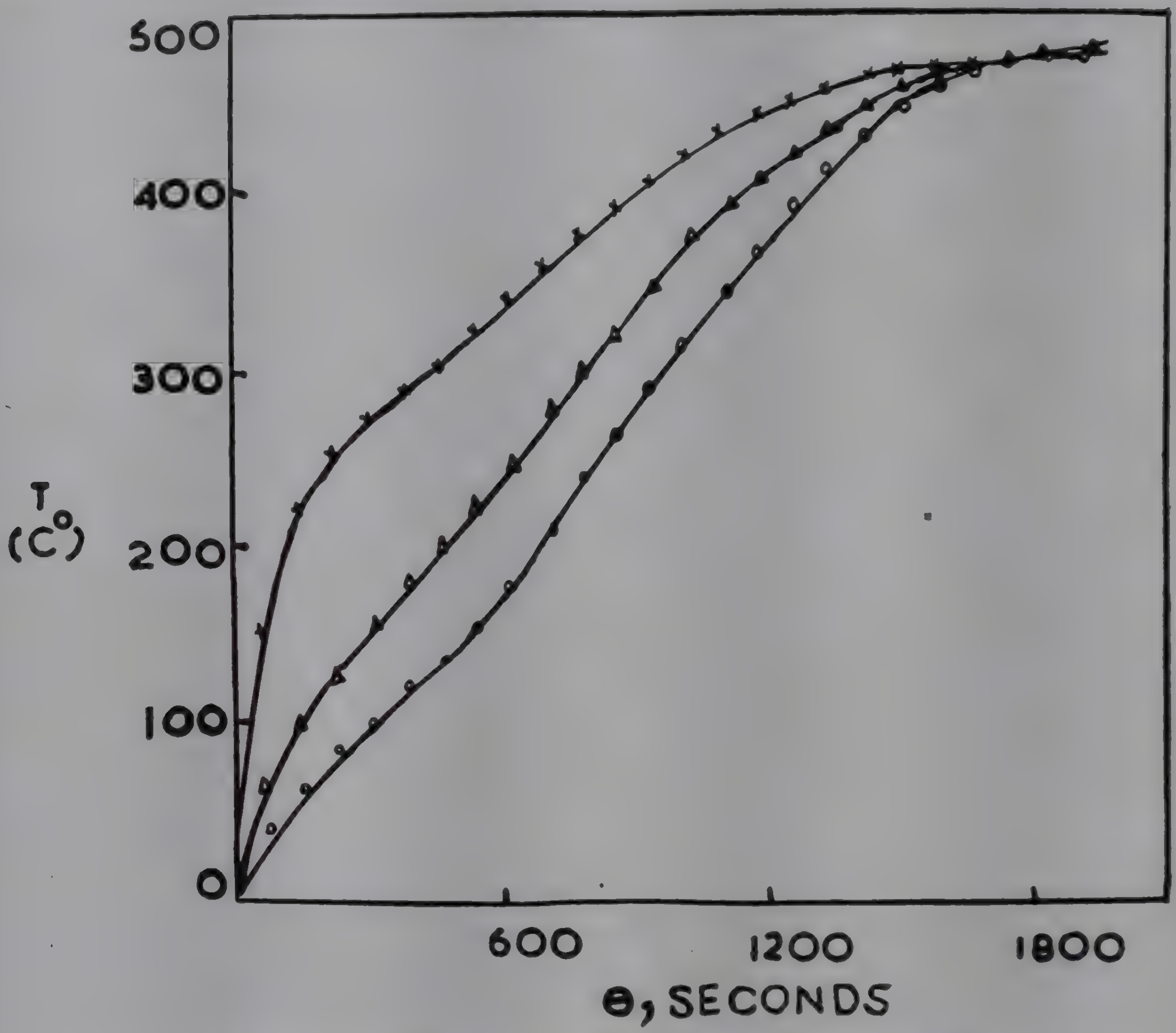

Fig. 13—T vs θ for briquette B: Volatile matter 13·7%; diam. 60 mm.; T_w 450°C.

$$\int_{T(t=o)}^{T(t)} \frac{\bar{C}_p(T)}{\lambda(T)}\, dT = \beta \int_o^t (T_1 - T_0)\, dt \tag{8}$$

If $$I = \int_o^t (T_1 - T_0)\, dt \tag{9}$$

then $$\int_{T(t=o)}^{T(t)} \frac{\bar{C}_p(T)}{\lambda(T)} dT = \beta \,.\, I \tag{10}$$

I is obtained from experimental data by employing graphical integration.

Two sides of (10) are differentiated by T as

$$\frac{\bar{C}_p(T)}{\lambda(T)} = \beta \frac{\delta I}{\delta T} \quad \ldots \tag{11}$$

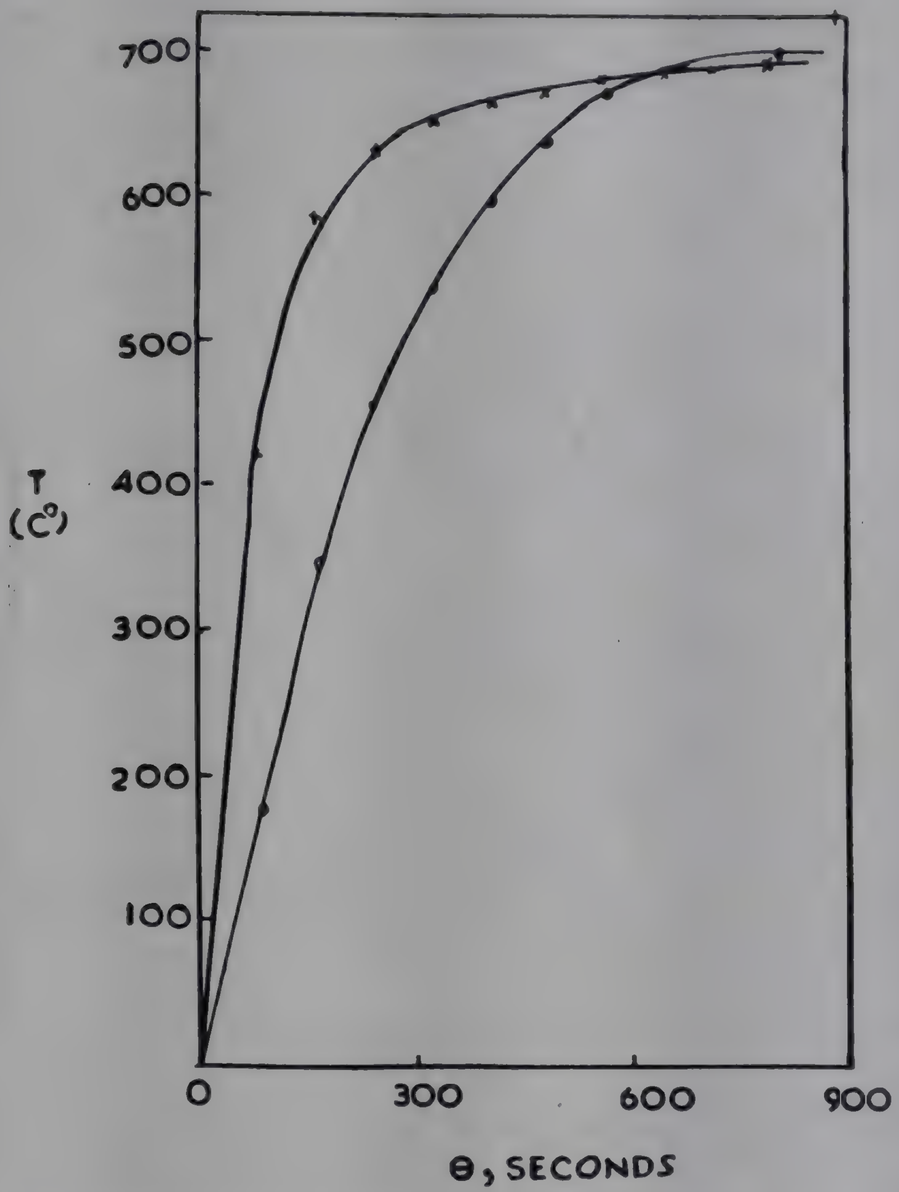

FIG. 14—T vs θ FOR BRIQUETTE B: Volatile matter 13·7%; diam. 30 mm.; T_w 650°C.

When the graph for I vs. Tav is drawn, $\dfrac{\delta I}{\delta Tav}$ is given by the gradient. Tav is equal to $\frac{1}{2}(T_0+T_1)$, $\bar{C}_p(T)$ is obtained from equation (11) if $\lambda(T)$, β, $\delta I/\delta T$ are previously known.

CALCULATION OF $\bar{C}_p$

Values of Physical Properties. The density and thermal conductivity of the sample (briquette) were determined.

Volatile matter and moisture of the briquette decrease on carbonization, but as the volume of the briquette also decreases, the density of briquette on carbonization is assumed to be nearly constant. The values of density obtained by actual measurement are shown in Table 2.

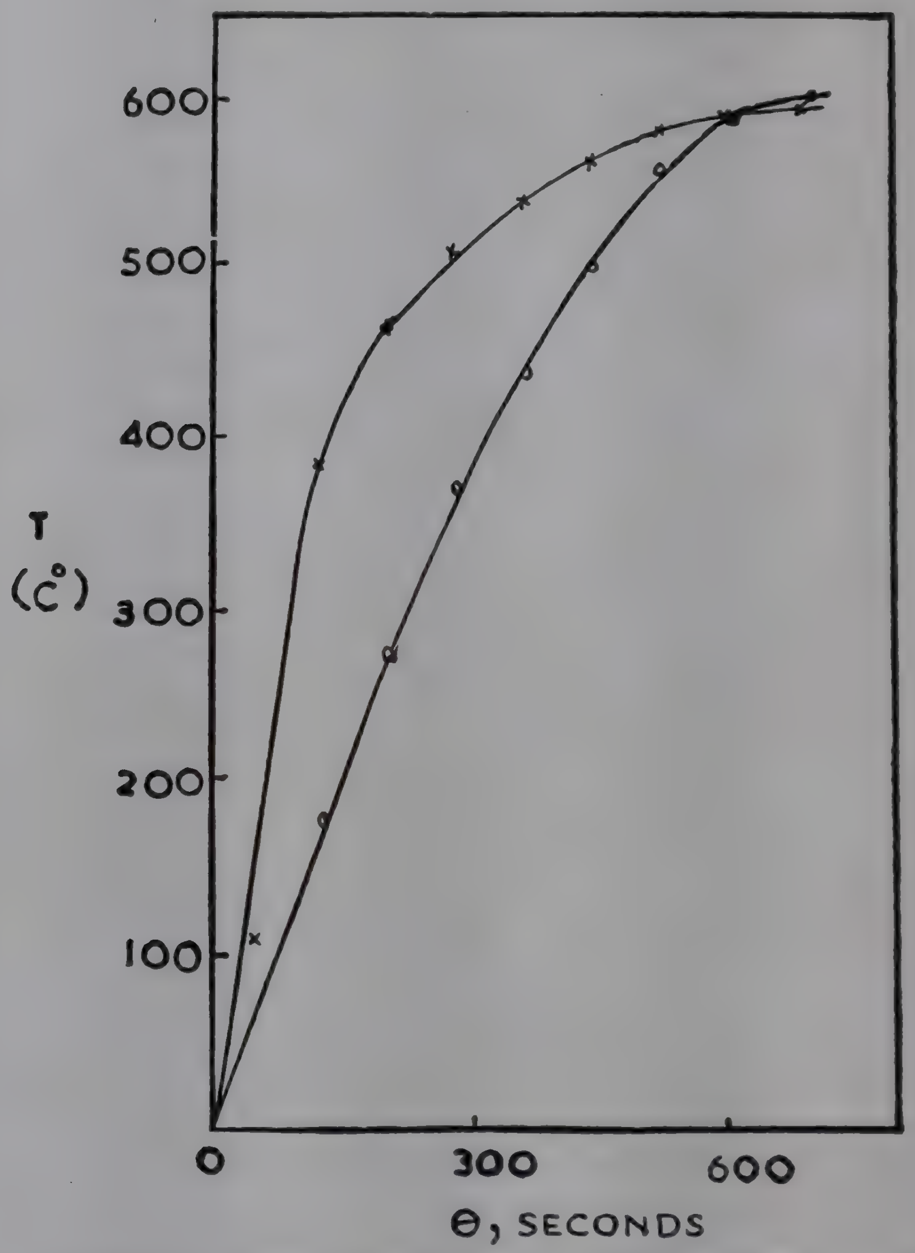

FIG. 15—T vs θ FOR BRIQUETTE B: Volatile matter 13·7%; diam. 30 mm.; T_w 550°C.

TABLE 2—DENSITY OF BRIQUETTE (kg./m.^{3})

Briquette 'A'	$1{\cdot}20\times10^3$
Briquette 'B'	$1{\cdot}20\times10^3$

As it is difficult to examine the thermal conductivity of the briquette at the temperature of carbonization, it was assumed to be the same as that of coke prepared from briquette. The value of thermal conductivity of coke at 550°C. is 0·98 (kcal./m.hr °C.).

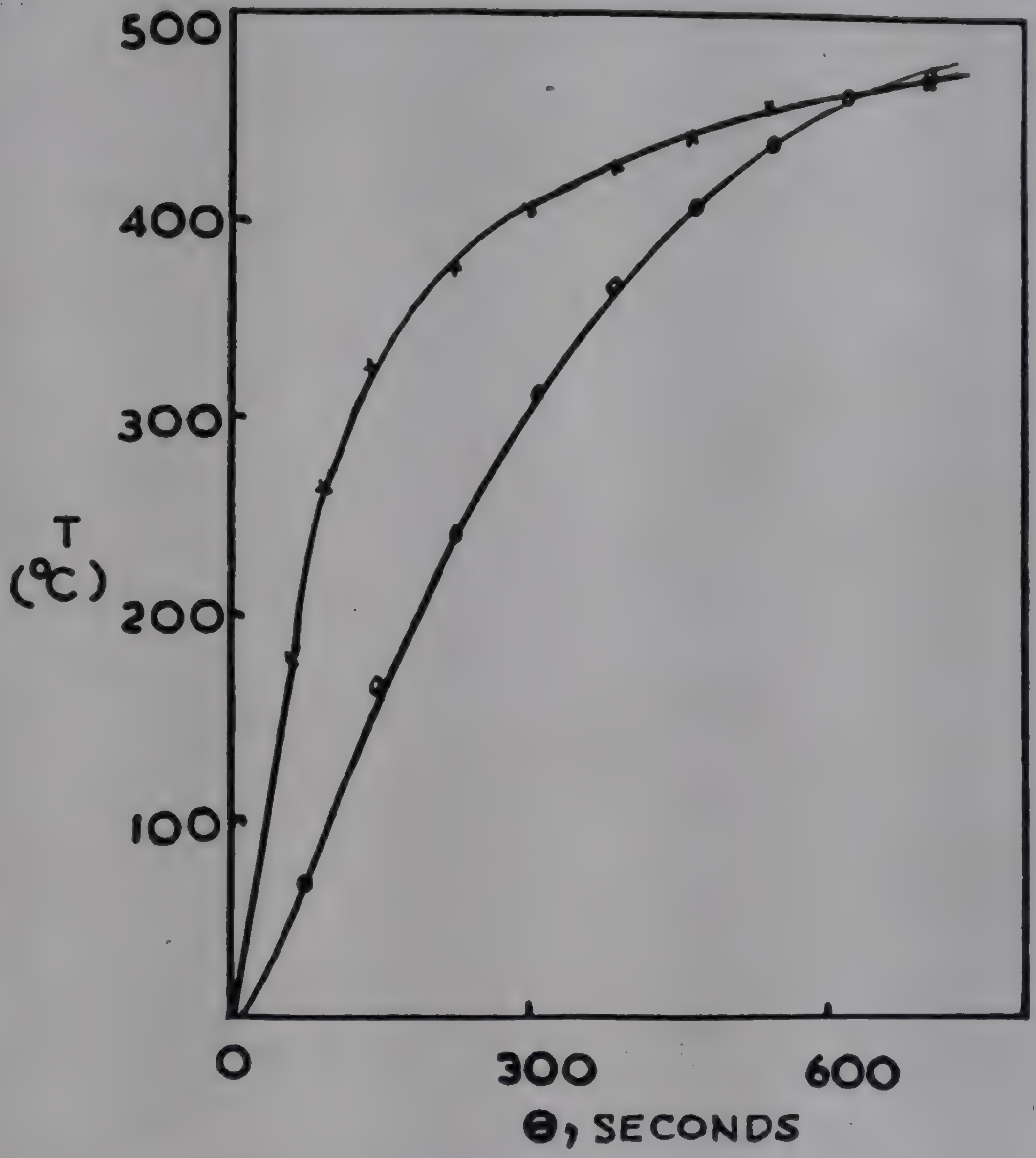

FIG. 16—T vs θ FOR BRIQUETTE B: Volatile matter 13·7%; diam. 30 mm.; T_w 450°C.

The values of β $(=6/\rho a^2)$ is shown in Table 3.

TABLE 3—VALUES OF β (m./kg.)

	a=0·03 (m.)	a=0·015(m.)
Briquette 'A'	5·55	22·22
Briquette 'B'	5·55	22·22

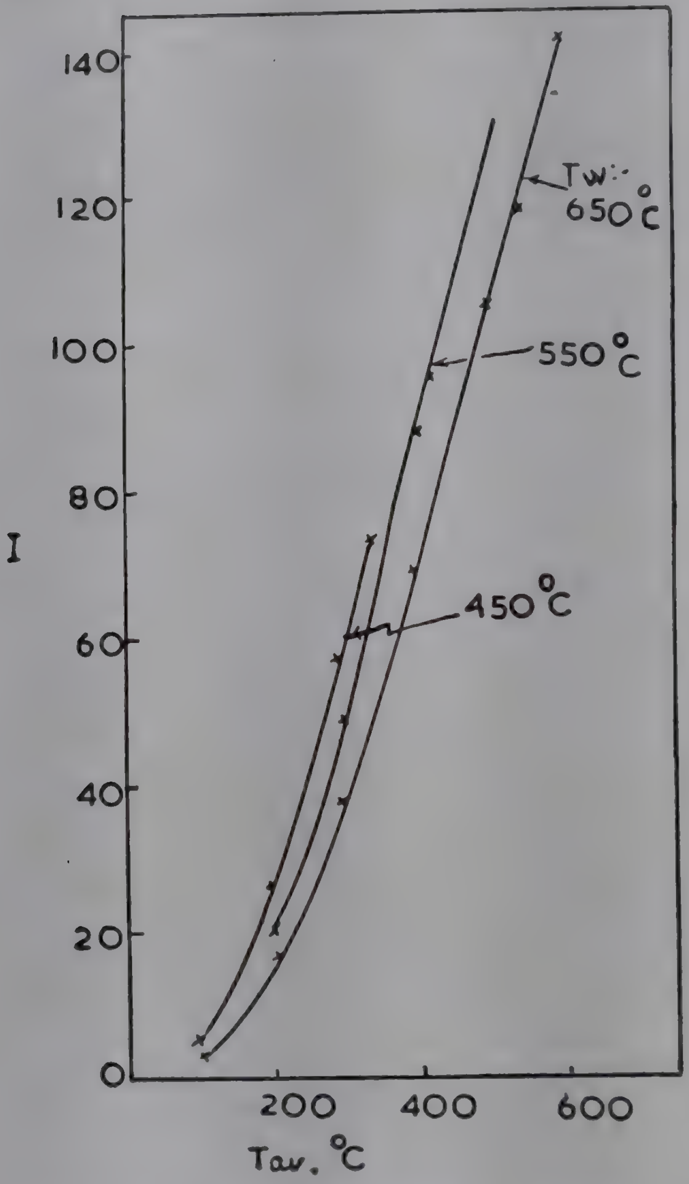

Fig. 17—I vs T_{av} for briquette A: Volatile matter 19%; diam. 60 mm.

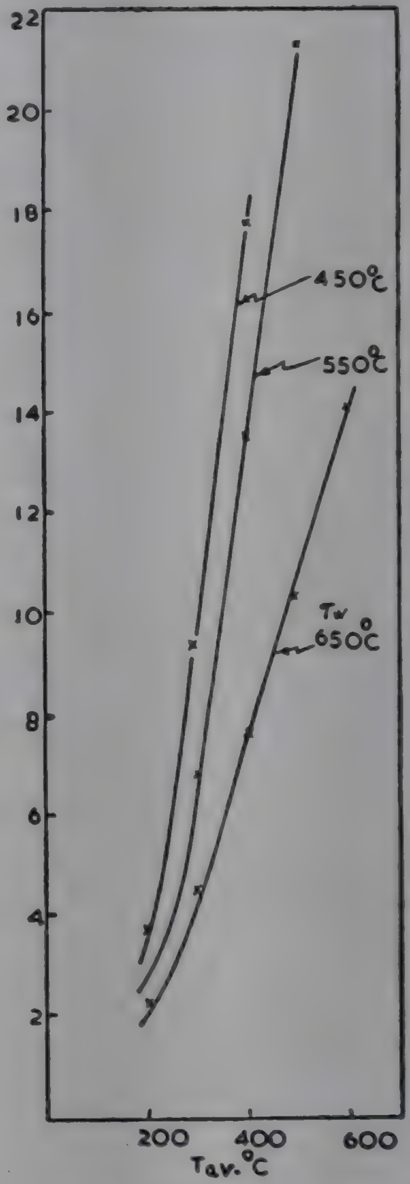

Fig. 18—I vs T_{av} for briquette A: Volatile matter 19%; diam. 30 mm.

The graphs of *I* vs *Tav* are shown in Figs. 17-20. The values of $\delta I/\delta Tav$ obtained from Figs. 17-20 are shown in Table 4.

TABLE 4—VALUES OF $\delta I/\delta Tav$

		650°C.	550°C.	450°C.
Briquette 'A'	D=60 mm.	0·300	0·357	0·352
do	D=30 mm.	0·030	0·064	0·073
Briquette 'B'	D=60 mm.	0·161	0·168	0·167
do	D=30 mm.	0·038	0·046	0·049

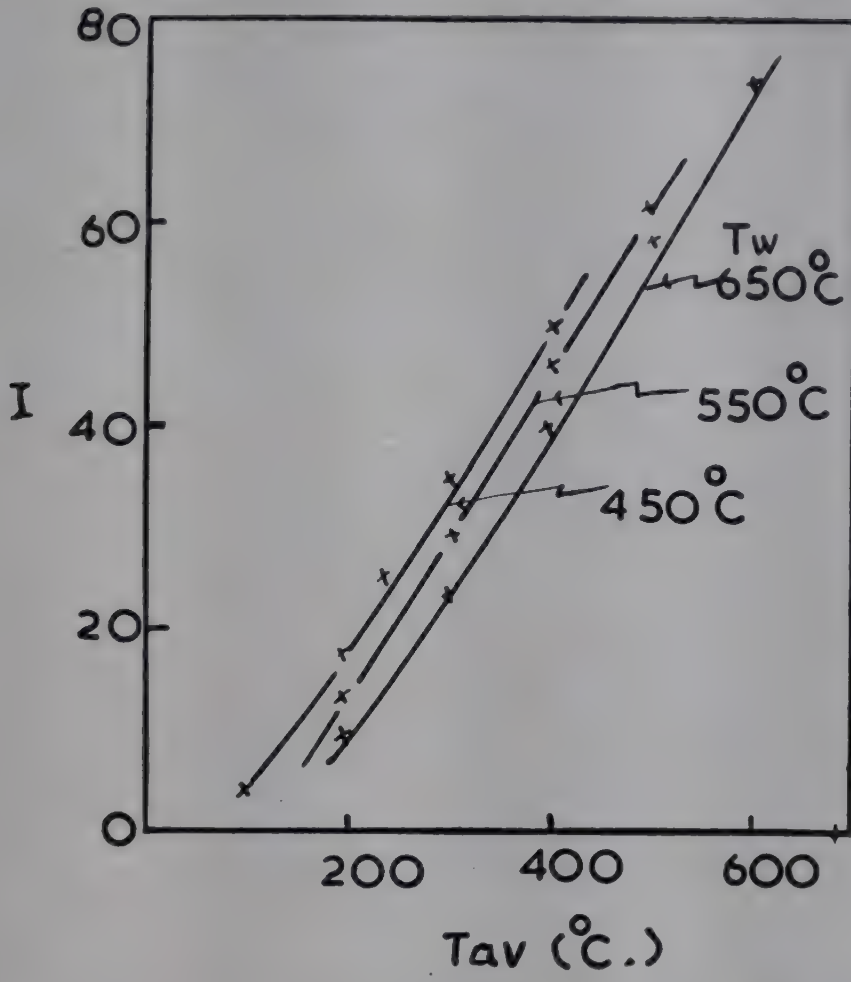

FIG. 19—I vs Tav FOR BRIQUETTE B: Volatile matter 13·7%; diam. 60 mm.

TABLE 5—VALUES OF $\bar{C}_p$ (kcal./m. hr °C.)

		650°C.	550°C.	450°C.	Mean
Briquette 'A'	D=60 mm.	1·64	1·94	1·91	1·83
do	D=30 mm.	0·66	1·39	1·60	1·22
Briquette 'B'	D=60 mm.	0·87	0·91	0·91	0·90
do	D=30 mm.	0·82	1·00	1·07	0·96

Values for overall specific heat $\bar{C}_p$ calculated by using the above values in equation (11) are shown in Table 5.

In the case of briquette A there is considerable difference between the values of $\bar{C}_p$ for the two sizes used. This could not be explained. With briquette B, however, the value of $\bar{C}_p$ agrees well. The mean value of $\bar{C}_p$ of briquette A is about 1·53 and that of B about 0·93. The volume of volatile matter of the sample causes such difference. As $\bar{C}_p$ is overall specific heat including the heat of carbonization, the value of $\bar{C}_p$ of briquette is considerably larger than that of the specific heat of coke or coal.

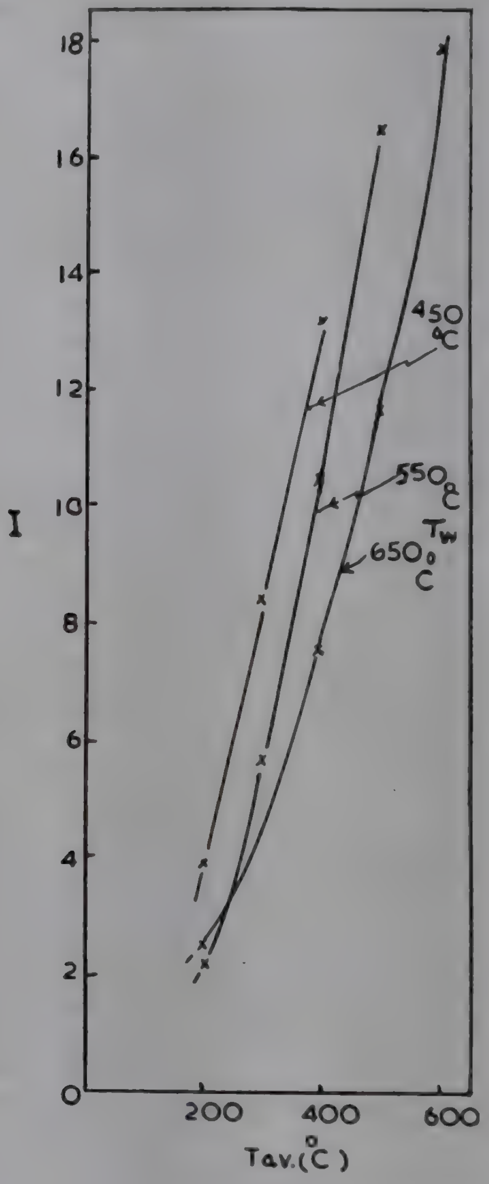

Fig. 20—I vs Tav for briquette B: Volatile matter 13·7%; diam. 30 mm.

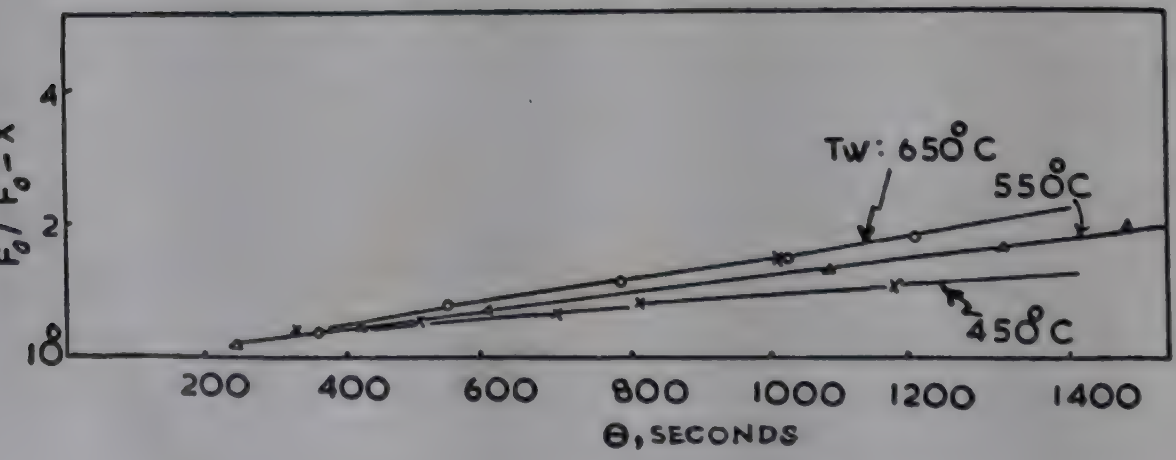

Fig. 21—F_0/F_0-x vs θ for briquette A (diam. 60 mm.)

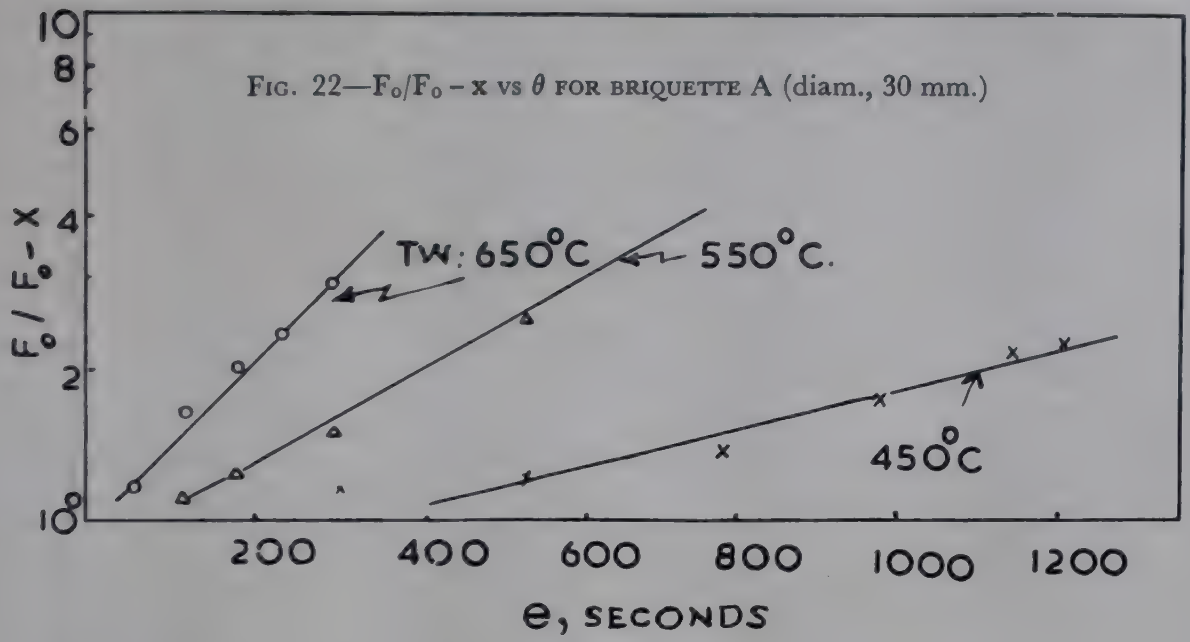

FIG. 22—$F_0/F_0 - x$ vs θ FOR BRIQUETTE A (diam., 30 mm.)

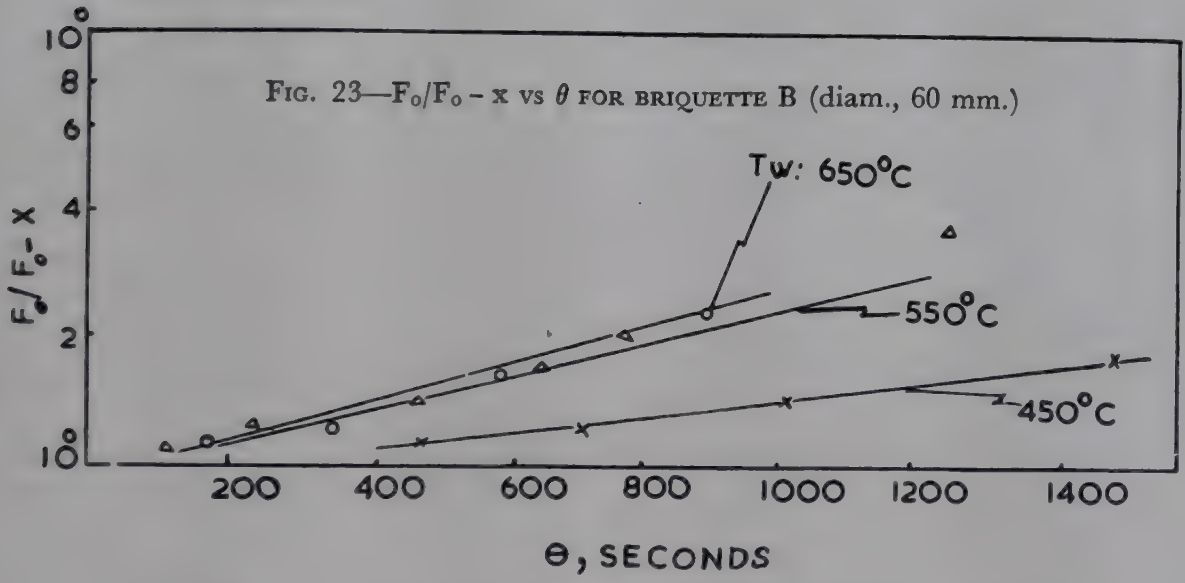

FIG. 23—$F_0/F_0 - x$ vs θ FOR BRIQUETTE B (diam., 60 mm.)

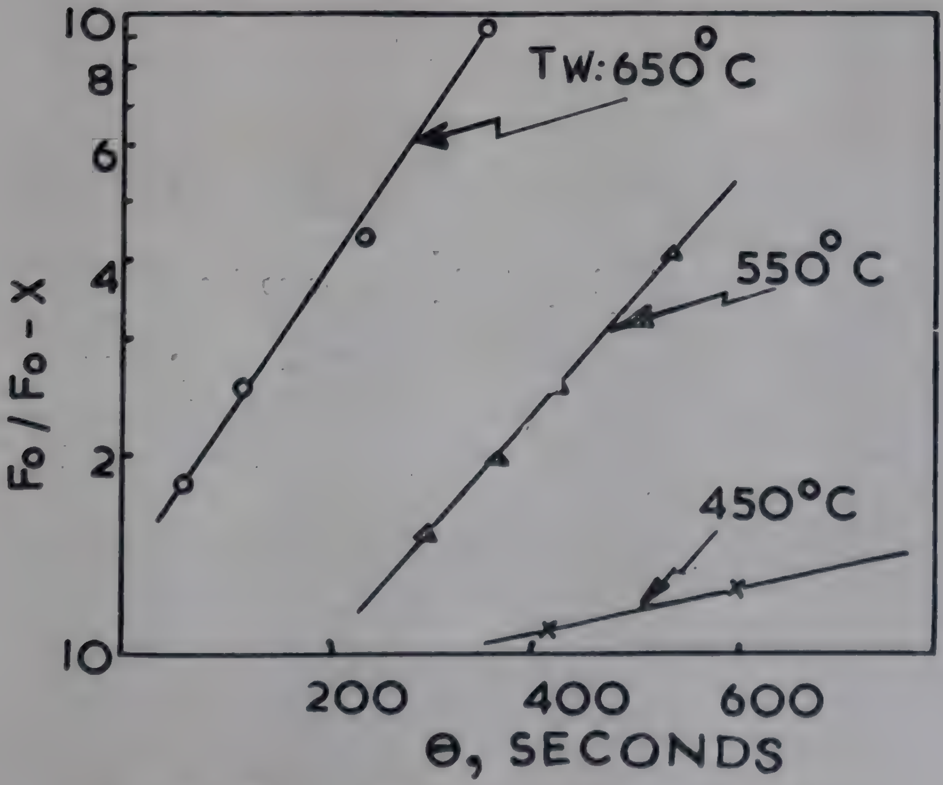

FIG. 24—$F_0/F_0 - x$ vs θ FOR BRIQUETTE B (diam., 30 mm.)

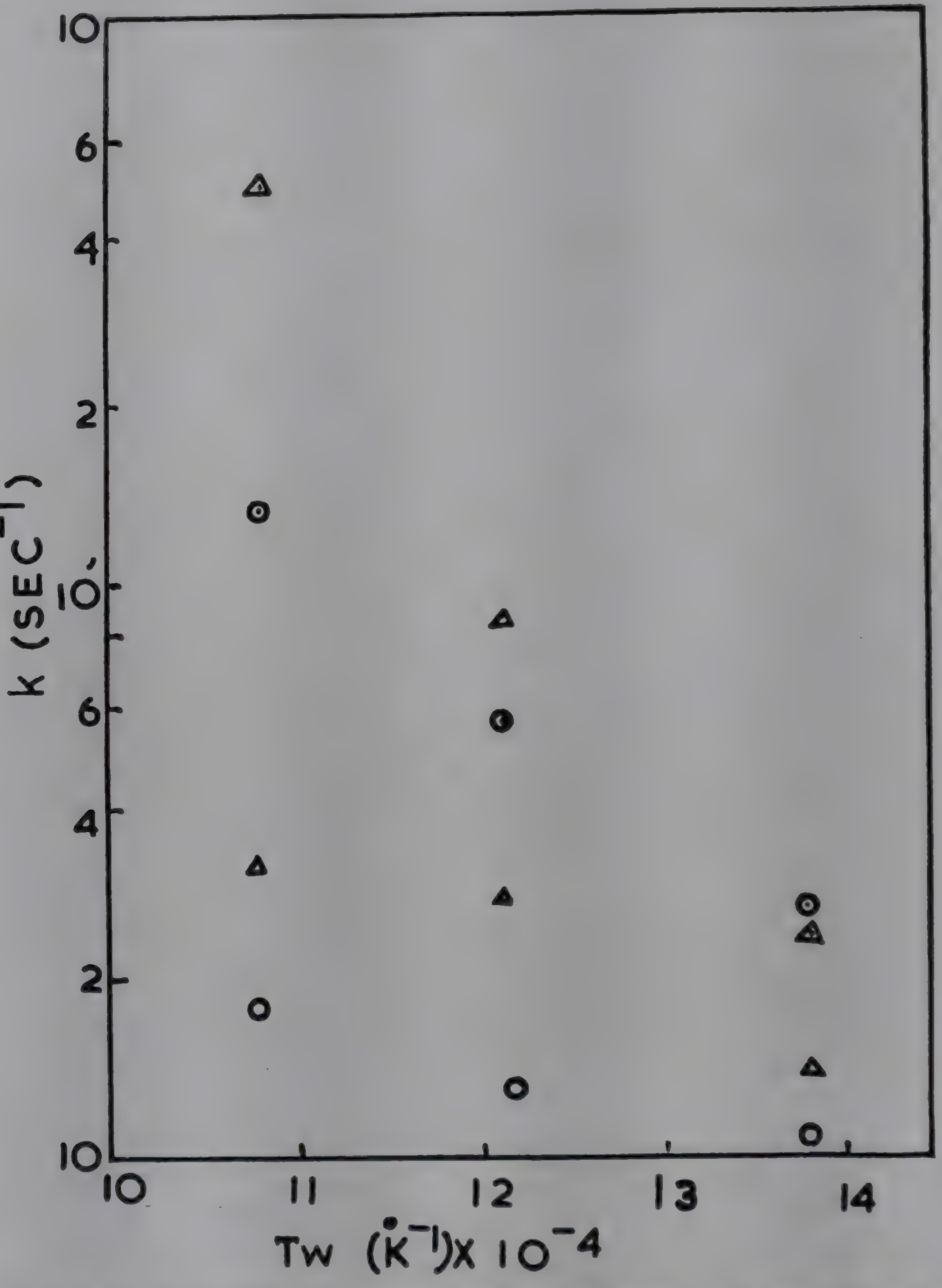

FIG. 25—k vs T_w °$K^{-1} \times 10^{-4}$: ○ Briquette A (diam., 60 mm.); ⊙ Briquette A (diam., 30 mm.); △ Briquette B (diam., 60 mm.); △ Briquette B (diam., 30 mm.)

As the heat of carbonization of briquette or coal cannot be measured easily, it was calculated by using $\overline{C}_p$.

Because overall specific heat is defined as $\overline{C}_p = C_p + Y\triangle H$ (where $Y\triangle H$ is heat of carbonization considering the reaction rate and C_p is specific heat of coke prepared from briquette or coal), heat of carbonization can be calculated.

For example, the heat of endothermic reaction of briquette A (from 450 to 550°C., D=60 mm.) was calculated to be about 168 kcal./kg. (where specific heat of coke is 0·25).

REACTION RATE COEFFICIENT k

The total volatile matter of briquette is regarded as the initial concentration and the volatile matter distilled is regarded as the reacted volume. The relationship between θ and (F_o/F_o-x) is shown in Figs. 21-24.

From Figs. 21-24, the l.t.c. can be regarded as the first order reaction, where the distilled volume is regarded as the change in concentration. Consequently the equation can be written as

$$\theta = \frac{1}{k} \ln \frac{F_o}{F_o - x} \qquad (12)$$

The reaction rate coefficients of l.t.c. carbonization obtained from this reaction are shown in Fig. 25. But these values are the reaction rate coefficients related to the temperature of furnace T_w.

ACKNOWLEDGEMENT

The authors thank Mr Chimura, the President of Asahi Coke Industrial Co. (Nagoya), and Mr Tetsuo Sakai for their helpful suggestions and discussion.

NOMENCLATURE

T : temperature (°C.)
V.M. : volatile matter
D : diameter of sample (mm.)
T_w : temperature of furnace (°C.)
$\bar{C}_p$: overall specific heat (kcal./kg. °C.)
ρ : density (kg./m.^{3})
t : time (hr)
λ : thermal conductivity (kcal./m. hr °C.)
r : length from centre to radius direction's point of sample (m.)
θ : time (sec.)
k : reaction rate coefficient (sec.$^{-1}$)
F_o : weight of V.M./weight of sample
x : weight of V.M. distilled/initial weight of sample

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Influence of Mineral Matter upon the Caking Properties of Coal : Part I*

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Experiments to study the influence of mineral matter on the caking properties of coal are reported. Addition of different minerals of fine size was found to decrease the dilatation and Roga-index, the effect increasing with decreasing particle size. Relationship between decrease in dilatation and quantity and particle size of mineral matter has been given in the form of an equation. Similar relationship for Roga-index has also been obtained. The relationships are useful to calculate the improvements in coking properties by the removal of mineral matter as a result of washing if there is no change in petrographic composition.

The caking properties of coal are influenced by various factors. A strong but sufficiently porous coke can only be obtained from a coal of particular rank having a suitable petrographic composition. The mineral matter in coal is also important as it reduces the caking properties of coal. The problem is of particular importance to India as the reserves of good coking coal are limited and high ash coal has to be washed to obtain coking coal. If the influence of mineral matter upon the caking property is known quantitatively, it will be possible to predict the improvement in caking qualities that can be effected by removal of a definite quantity of mineral matter.

Some qualitative idea of the effect of mineral matter upon the caking properties can be obtained from published literature[1–6], specially the papers of Lambris and Marie[7], Bahr and Fallbohmer[8], and Barking and

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Eymann[9]. They observed that with certain types of coal, which gave a very porous and weak coke, the addition of mineral matter to a certain extent decreased the porosity and increased the strength of the coke. But further addition of mineral matter decreased the strength of the coke. No attempt was, however, made by them to evaluate a quantitative relationship between the mineral matter and the change in caking property as indicated by dilatation or plasticity or hardness by any of the standard methods. The present investigation attempts to find out the effect of common minerals present in coal upon the caking properties and to obtain a quantitative relationship between mineral matter and caking property of coal.

The main difficulty in such studies is to obtain coal samples having different mineral matter content but of the same rank and petrographic composition. Moreover, the quality of mineral matter may also vary from sample to sample. It is for this reason that from the available data no correlation between the mineral matter content and the caking property has been possible. To overcome these difficulties, in the present study, experiments were conducted using mixtures of coal and mineral matter. Caking properties were measured by determining dilatation and Roga-index according to international standard methods[10]. The decrease in dilatation and Roga-index have been estimated by adding different quantities of standard sand (obtained from the British Coal Research Board), which is used for measuring the agglutinating index of coal.

COAL SAMPLES

The samples of coal used in the present investigation are from Ruhr area in Germany and from Dishergarh and Loyabad mines in India. The analysis of the coal samples is given in Table 1. Coal samples from Germany were stored in an atmosphere of nitrogen and those from India were for the first six months stored under water and later in an atmosphere of nitrogen. It has been observed that even by storing under water and nitrogen there

TABLE 1—ANALYSIS OF THE COALS USED IN THE INVESTIGATION

ORIGIN	RUHR AREA (Germany)			INDIAN COALS	
	Coking coal I	Gas coal II	High ash gas coal III	Loyabad IV	Dishergarh V
Ash, %	5·6	5·9	26·0	16·4	12·3
Moisture, %	0·7	1·8	1·0	1·3	1·7
Carbon, %	82·7	81·1	..	72·0	..
Hydrogen, %	4·75	4·67	..	4·4	..
Vol. matter (moisture and ash-free basis), %	23·6	28·2	29·6	26·0	42·7
Dilatation, %	89·0	98·0	nil	43·0	42·0
Roga-index, %	80·0	74·0	21·5	56·0	65·0

is some decrease in dilatation of the powdered coal although no appreciable decrease in Roga-index has been observed. Therefore it was found necessary to find out the dilatation and Roga-index before every set of experiments.

EXPERIMENTS, OBSERVATIONS AND DISCUSSION

Effect of Quantity of Mineral Matter. The effect of addition of different quantities of sand (size 0·042 to 0·11 mm.) on the dilatation of the coal is shown in Figs. 1 and 2. It is observed that the addition of sand reduces the dilatation. It can be seen from Fig. 2 that the percent dilatation and the amount of sand added follows a straight line relationship unless the percentage of sand added is very high (more than 30 per cent).

The decrease in dilatation may be attributed also to the decrease in the quantity of coal in the coal pencil (because by the addition of sand a corresponding quantity of coal is decreased in the sample). A set of experiments with reduced quantity of coal (without sand) is performed and shown

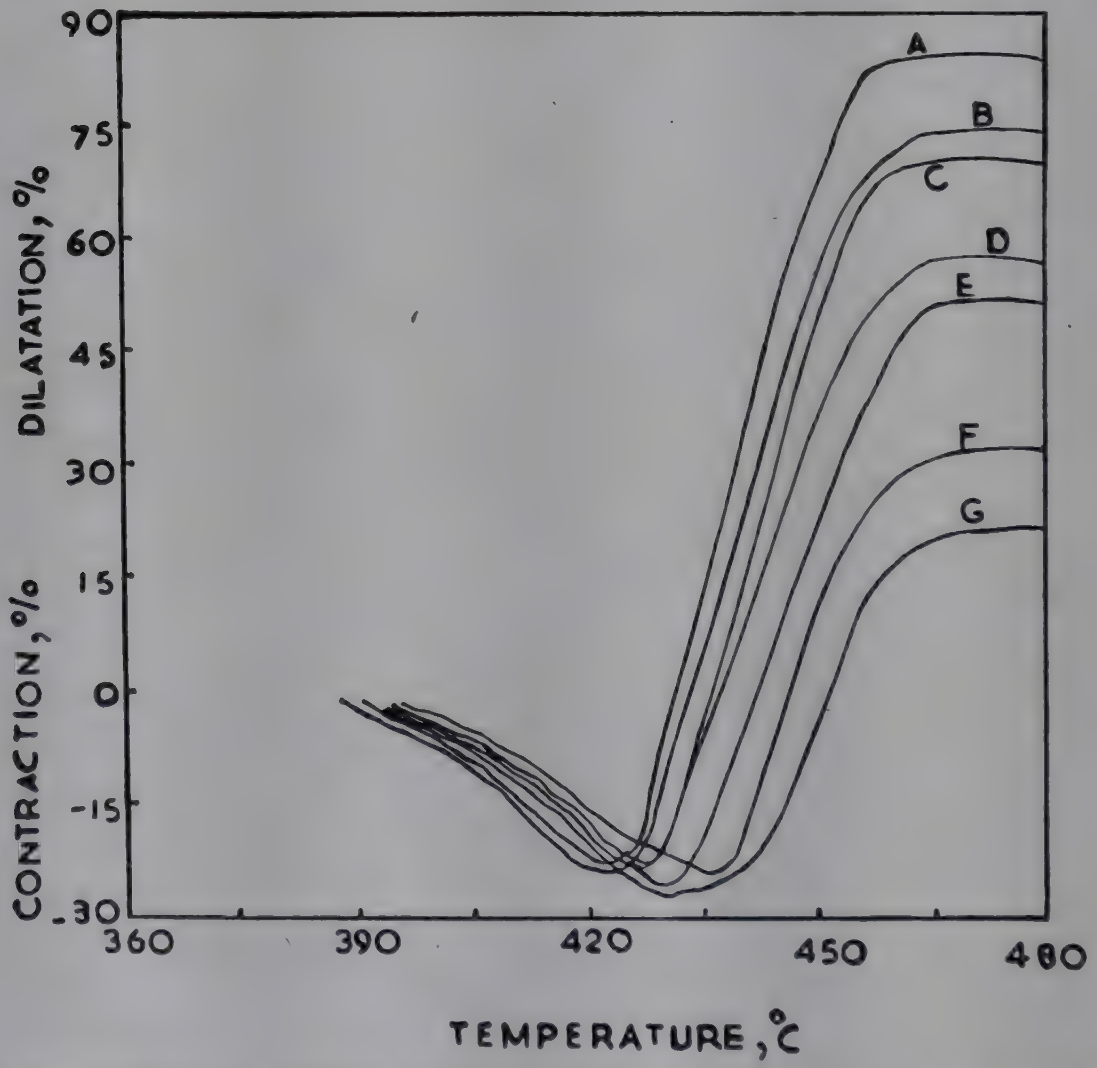

Fig. 1—Influence of addition of sand upon the dilatation curves of coal: Sand size: 0·042—0·1 mm. Sand content: A—0%; B—5%; C—10%; D—15%; E—20%; F—30%; G—40%

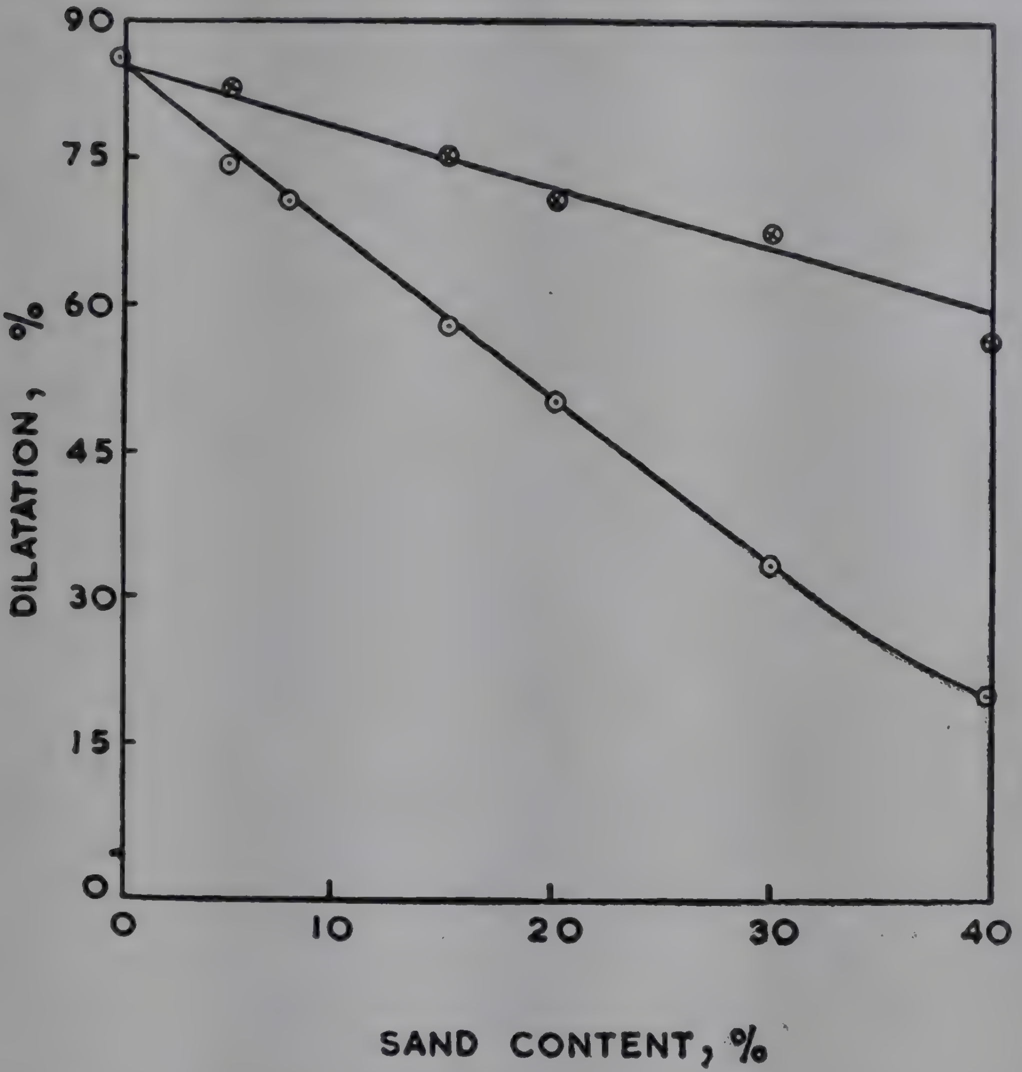

Fig. 2—Variation of dilatation with the addition of sand: ⊙ Measured dilatation, %; ⊕ Calculated dilatation, %

TABLE 2—DILATATION OF COAL AND SAND MIXTURE

Quantity of sand, wt %	Softening point, °C.	Resolidifying point, °C.	Contraction %	Dilatation %
0	386	460	24	84·5
5·0	386	463	23	74·5
7·5	386	463	23	71·0
15·0	386	466	24	58·0
20·0	386	466	26	50·5
30·0	386	466	26	34·0
40·0	386	437	24	21·0

in Fig. 2. A comparison of the two curves shows that the fall in dilatation is not merely due to the decrease in the coal content but also that the mineral matter present has a hindering effect upon the dilatation of coal.

Effect of Particle Size of Mineral Matter. Since the mineral matter present in coal is usually of very fine size and not always of the same size, it will not suffice to know the effect of quantity of mineral matter alone, but the effect of size of the mineral matter also must be found out. The result of addition of sand of different particle sizes in different amounts is given in Table 3 and shown in Figs. 3 and 4. It is found that as the size of sand is

TABLE 3—DILATATION OF COAL AND SAND MIXTURE—EFFECT OF VARIATION OF PARTICLE OF SAND: DILATATION OF COAL WITHOUT SAND —90%

Sand content, wt % (in mixture)	Contraction			Dilatation		
	5	10	20	5	10	20
Particle size of sand, mm.						
0·2 to 0·3	25	26	24	82·0	76·5	67·0
0·042 to 0·1	23	27	25	81·0	73·0	56·0
0·02 to 0·042	25	24	27	76·0	68·0	44·0
<0·02	23	26	25	75·0	58·5	30·0

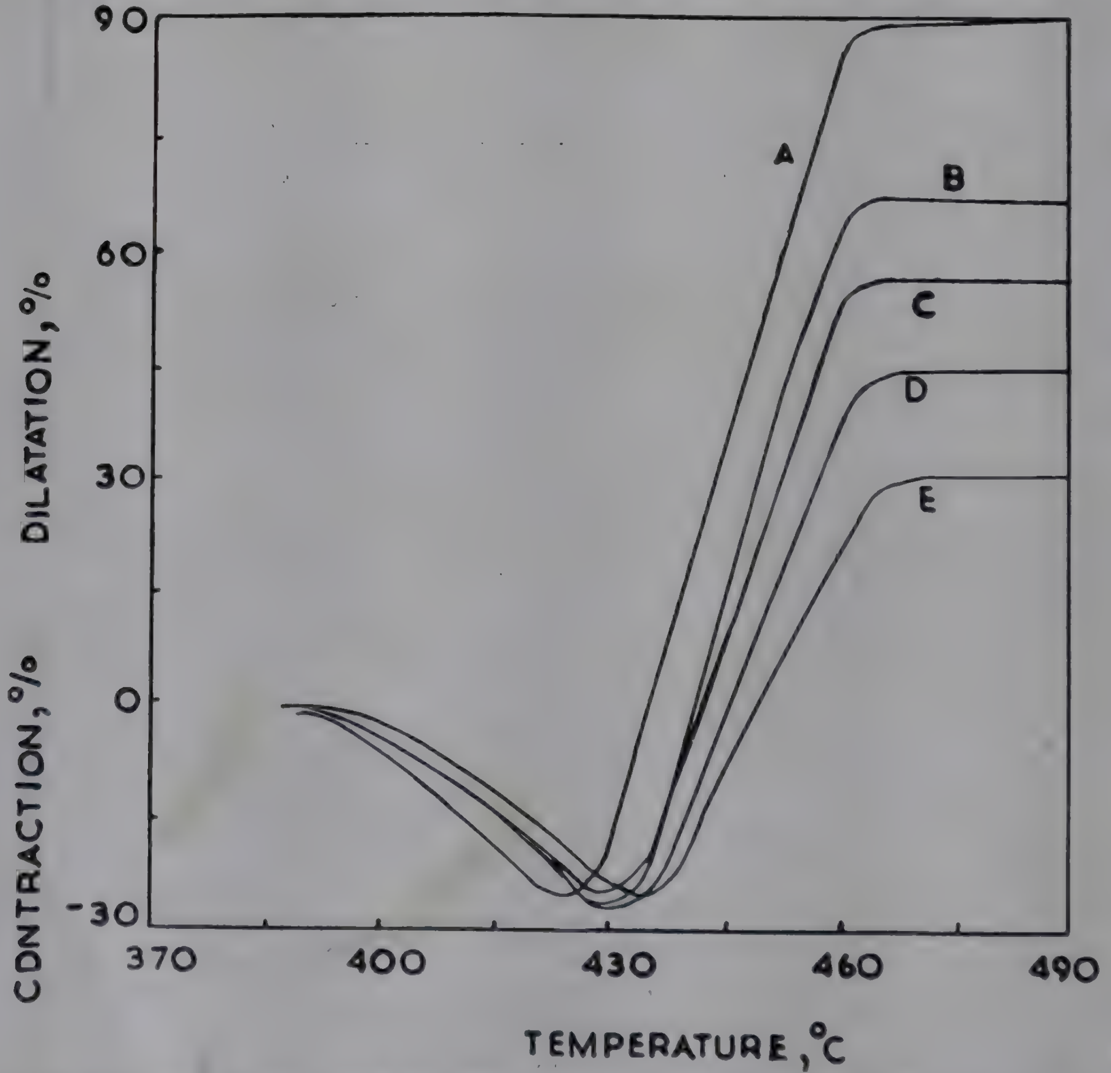

FIG. 3—DILATATION CURVES FOR COAL-SAND MIXTURE WITH SAND OF DIFFERENT SIZES: Sand sizes: (A) Without sand (B) 0·2—0·3 mm. (C) 0·042—0·1 mm. (D) 0·02—0·042 mm. (E) <0·02 mm. Sand content—20%

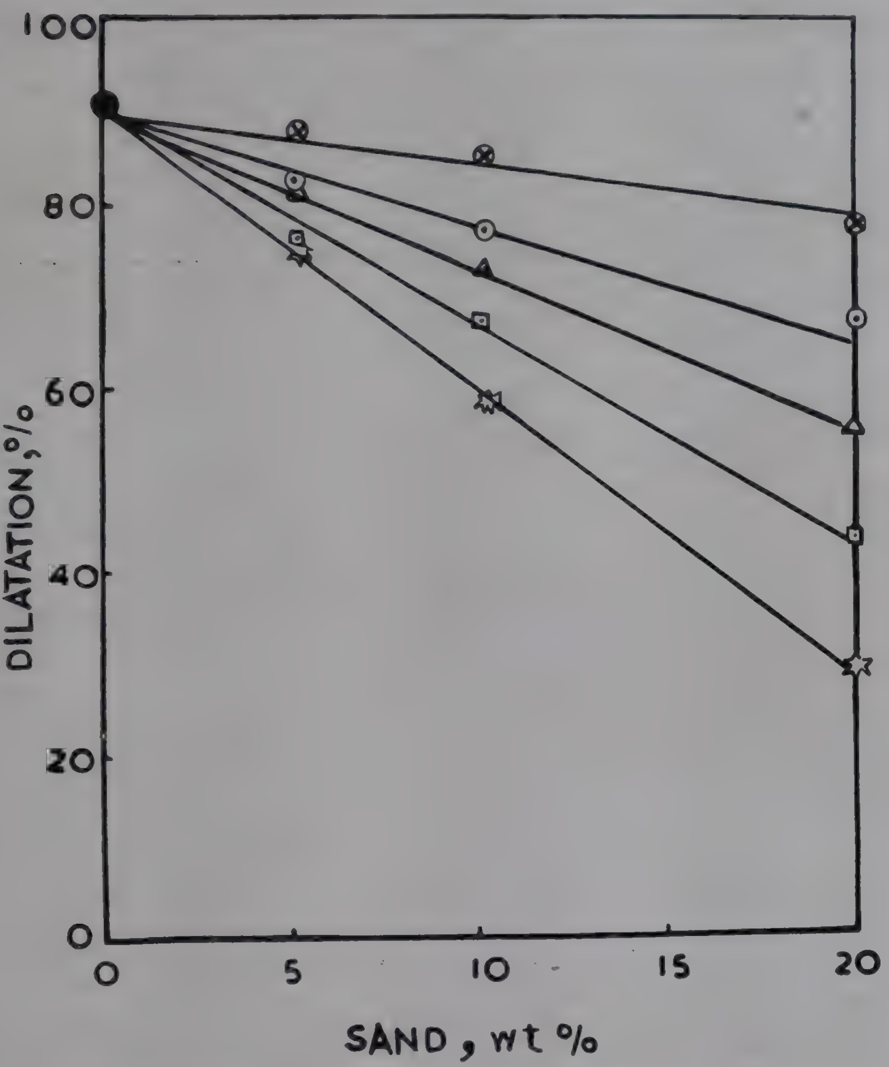

Fig. 4—Variation of the dilatation depending upon the size and content of sand: Sand sizes: ⊙ 0·2—0·3 mm.; △0·042—0·1 mm.; ⊡ 0·02—0·042 mm.; ✩ <0·02 mm.

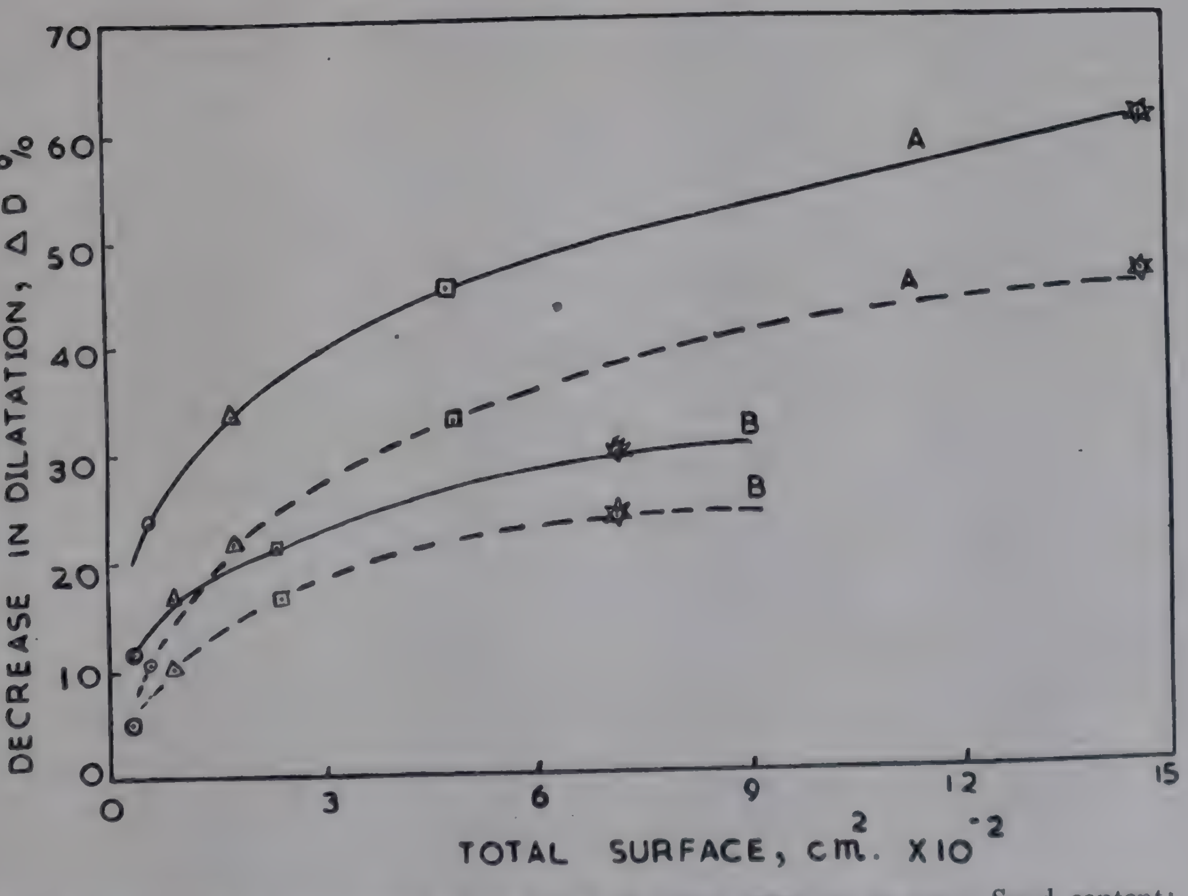

Fig. 5—Decrease in dilatation as fraction of total surface of sand: Sand content: A—20 wt %; B—10 wt %. Sand size: ⊙ 0·2—0·3 mm.; △0·042—0·1 mm.; ⊡ 0·02—0·042 mm.; ✩ <0·02 mm.; — Measured Dilatation; ... Calculated Dilatation

TABLE 4—THE VARIATION OF DILATATION OF COAL-SAND MIXTURE AS A FUNCTION OF THE SURFACE OF SAND

(Calculated from Table 2)

PARTICLE SIZE OF SAND, mm.	SPECIFIC SURFACE		TOTAL SURFACE OF SAND (F) AND THE CORRESPONDING DECREASE IN DILATATION ($\triangle D$) WITH 5, 10, AND 20% SAND					
			5%		10%		20%	
d (mm.)	d_{mean}	a_f cm.²/gm.	F, cm.²	$\triangle D$	F, cm.²	$\triangle D$	F, cm.²	$\triangle D$
0·2 -0·3	0·2600	87	11·4	6·0	23·3	12	47·7	24
0·042-0·1	0·075	303	39·8	8·5	81·7	17	167·0	34
0·02 -0·042	0·026	870	114	11·5	233·0	23	477·0	46
<0·02	0·0085	2660	349·0	15·0	712·0	30	1460·0	60·5

d_{mean} = diameter at 50 per cent point in Rosin-Rammlar distribution curve.

$a_f = \frac{6}{d}\gamma$, where $\gamma = 2{\cdot}65$, and shape factor $=1$.

TABLE 5—THE VALUES OF THE CONSTANTS k AND n FOR THE ADDITION OF DIFFERENT AMOUNT AND DIFFERENT SIZES OF SAND

SAND CONTENT, %	(mm.) d_{mean}	(mm.) d_2 mean	n	k
5	0·26	0·0085	0·267	0·836
10	0·026	0·075	0·282	0·820
20	0·0085	0·075	0·268	0·807

reduced, the effect on dilatation becomes more pronounced indicating that the effect increases with the increase in the surface area of sand (Fig. 5). In order to find out the overall effect, that is the effect of total surface of sand, the decrease in dilatation has been plotted against the total surface of sand on a log-log scale (Fig. 6).

From Fig. 6 it is clear that the logarithm of the decrease in dilatation is proportional to the logarithm of the specific surface$=6/\gamma d$, where γ is the specific gravity and d is the average particle diameter.

It follows, therefore, that when γ is constant, the decrease in dilatation is an exponential function of $\frac{1}{d}$, i.e.

$$\triangle D = k_1 \cdot \left(\frac{1}{d}\right)^n \tag{1}$$

where $\triangle D$ is the decrease in dilatation, d is the average particle diameter, mm.; k_1 and n are constants.

From Fig. 2 it has already been found that the decrease in dilatation is proportional to the quantity of sand added, or

$$\triangle D = k_2 . G \qquad (2)$$

where G = sand content, per cent

k_2 = constant.

By combining equations 1 and 2, when both quantity and particle size of sand vary,

$$\triangle D = k . G . \left(\frac{1}{d}\right)^n \qquad (3)$$

where k is a constant.

With the help of this equation the values of constants were calculated for the addition of different amounts of sand of different particle sizes. The values are given in Table 5.

It can be seen that the values of the constants are nearly same. Taking the values for the constants as $n=0{\cdot}27$ and $k=0{\cdot}82$, the decrease in dilatation by the addition of sand have been calculated and given in Table 6. From the table it can be seen that the measured and the calculated values for the decrease in dilatation are nearly same. It will, therefore, be possible to calculate the decrease in dilatation due to the minerals of different sizes present in coal by evaluating the values of the constants (method given in subsequent part).

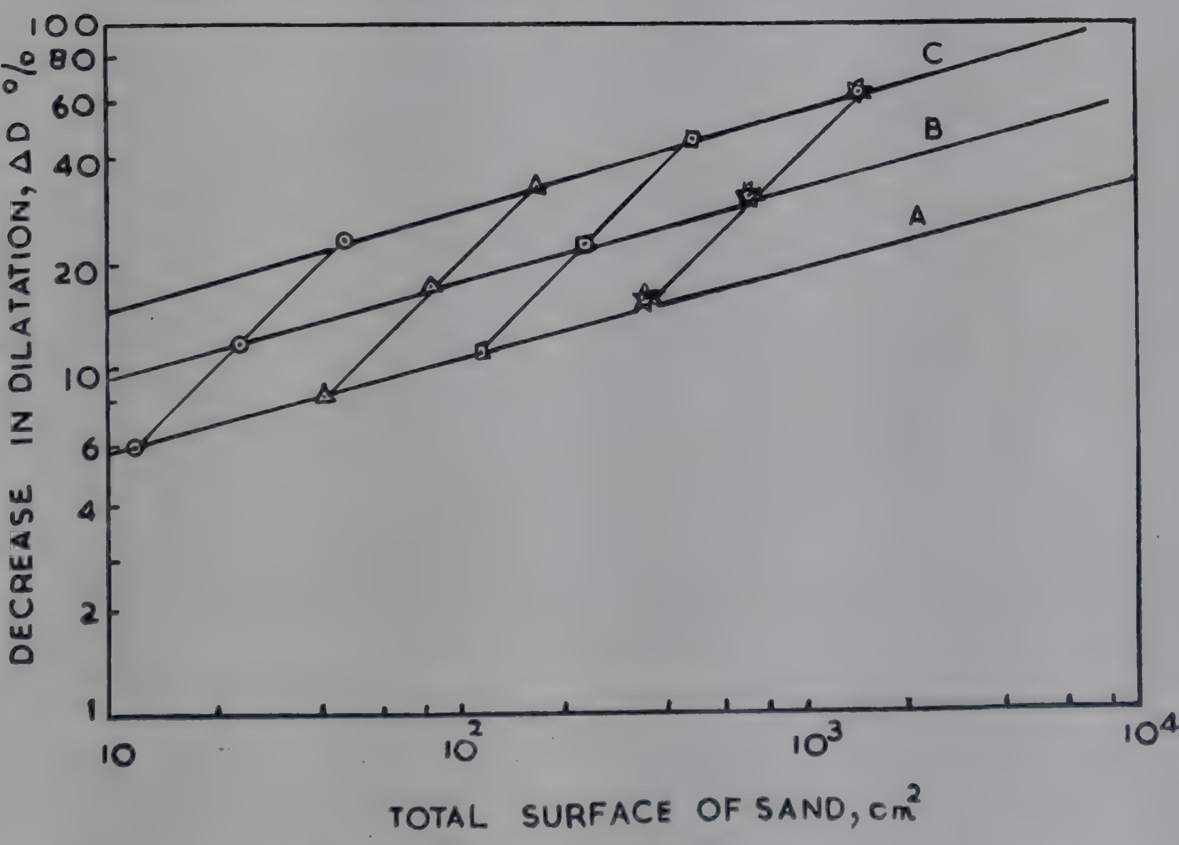

FIG. 6—DECREASE IN DILATATION DEPENDING UPON THE SAND SURFACE AND SAND QUANTITY: Sand content: A—5%; B—10%; C—20%. Sand size: ⊙ 0·2—0·3 mm.; △ 0·042—0·1 mm.; ⊡ 0·02—0·042 mm.; ☆ <0·02 mm.

TABLE 6—COMPARISON OF THE MEASURED AND CALCULATED DILATATION

Sand content, wt %	Particle size, mm.	Dilatation of coal without sand, %	Decrease in dilatation ΔD	
			Calculated	Measured
5	0·26	90	6	9
10	0·0085	90	30	31·5
20	0·0085	90	60	60·5
10	0·0015	78	48	48

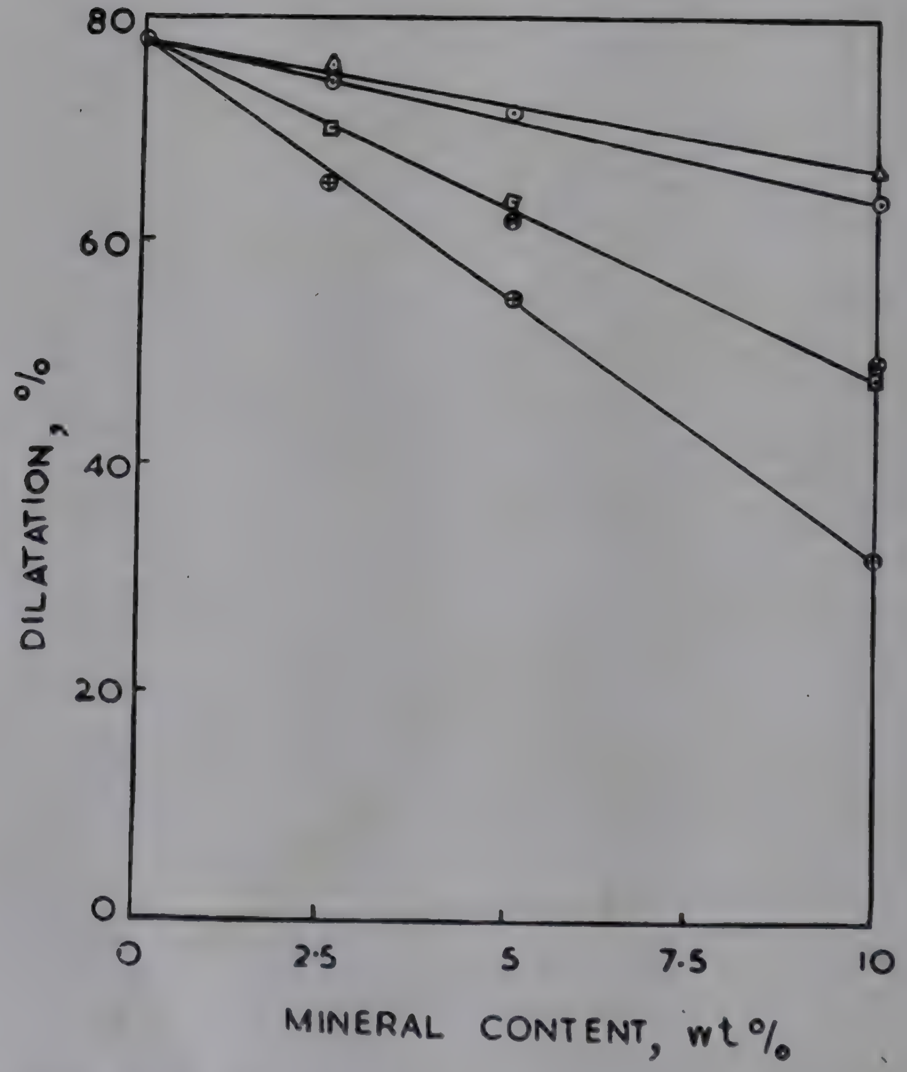

Fig. 7—Variation of dilatation with the addition of different minerals: △Sand, Calcite, ⊙ Pyrites, ⊗ Siderite, ⊡ Haematite, ⊕ Limonite; Particle size in all cases 0·042—1·1 mm.

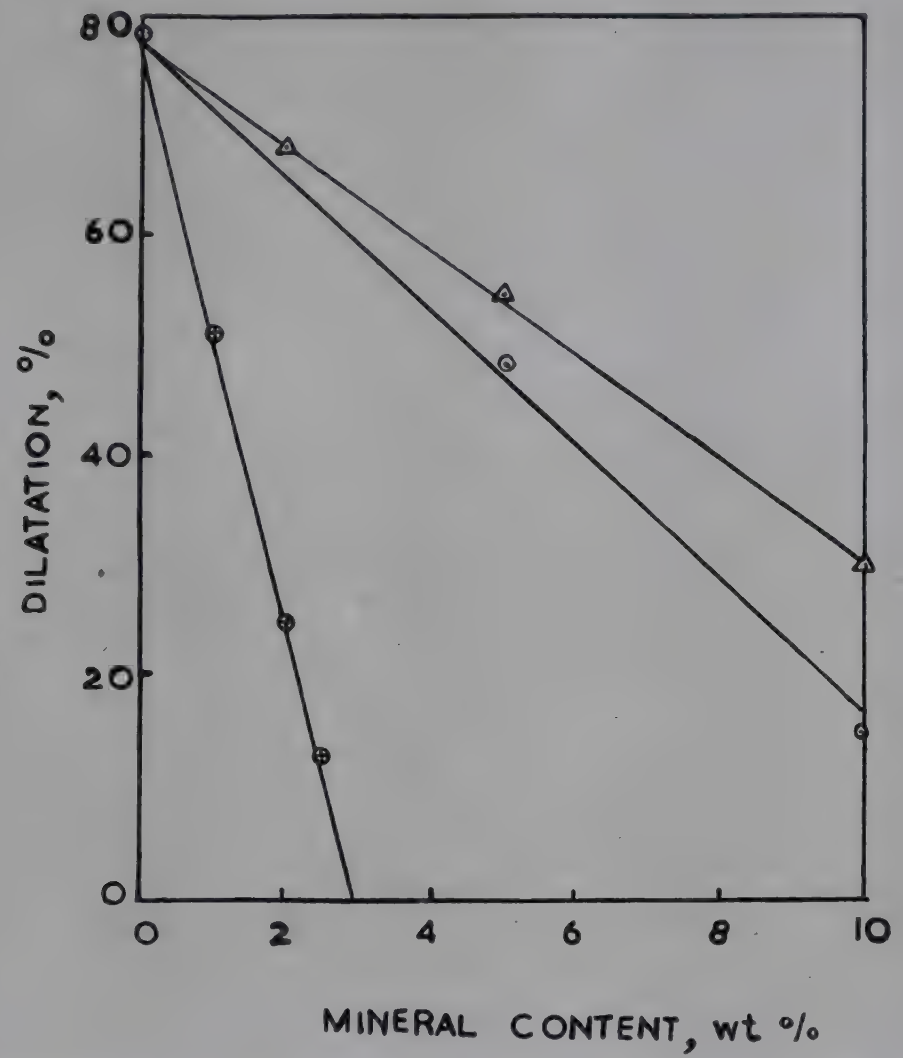

FIG. 8—VARIATION OF DILATATION WITH THE ADDITION OF MINERALS OF VERY FINE SIZES: Particle sizes: △ Sand $<3\mu$, ⊙Kaolin $<2{\cdot}5\mu$, ⊕Limonite $<1{\cdot}5\mu$

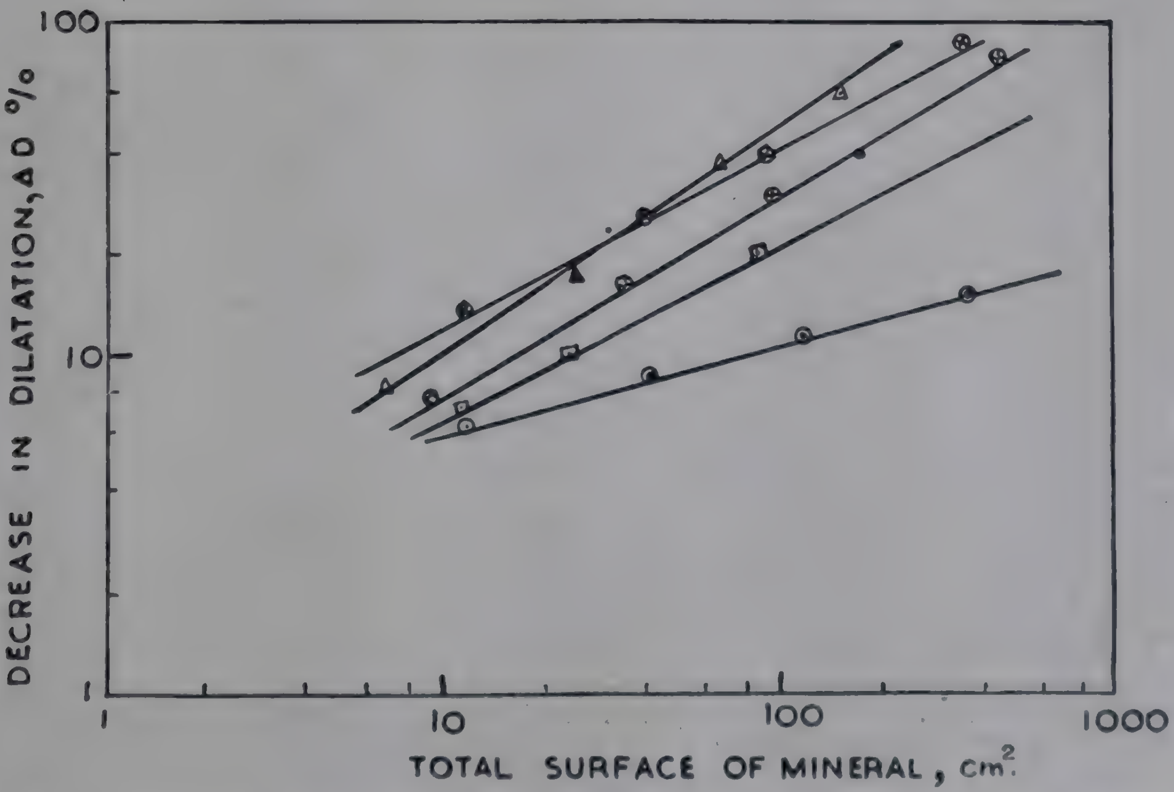

FIG. 9—VARIATION OF THE DECREASE IN DILATATION WITH THE TOTAL SURFACE OF THE ADDED MINERALS: ⊙Sand, ⊡ Pyrites, ⊕Siderite, △ Haematite, ⊗ Limonite

Effect of Other Minerals. Almost all the minerals occurring in nature can be found in coal, but only some of them like kaolin, quartz, calcite and some iron minerals occur in appreciable quantity making up more than 90 per cent of the total minerals present. Experiments were done to study the effect of other common minerals of coal, and the relationship obtained using sand has been verified. The minerals used were pyrites (FeS_2), siderite ($FeCO_3$), calcite ($CaCO_3$), limonite ($FeO.OH$), haematite (Fe_2O_3). The minerals of different sizes are added in different amounts to coal and the decrease in the dilatation noted (Table 7 and Figs. 7, 8). The effect of deterioration of caking property by iron oxide minerals particularly by limonite has been found to be very high. The influence of pyrites and that of calcite is almost the same as that of sand. The relationship developed by using sand can also be applied in the case of other minerals investigated (Fig. 9). In Table 8 the calculated values of the constants for the different minerals and the calculated and experimentally determined values for decrease in dilatation are given. It can be seen that unless the particle size is very fine the results are in agreement. In the case of very fine sizes the experimentally determined values are lower because due to the agglomeration of the fine particles the total effective surface is diminished and less decrease in dilatation observed.

Influence of Mixture of Minerals. Since the effect of different minerals will be simultaneous, experiments were conducted to study how the different minerals affect one another.

A mixture of sand and kaolin, and of sand, kaolin and limonite were added to the coal and the decrease in dilatation noted. The calculated dilatation (sum of the individual effects) and the experimental values are shown in Table 9. It is noticed that the total effect of a mixture of minerals is the sum of the individual effect of mineral.

Calculation and Prediction of Dilatation of Washed Coal. It has been found by the earlier sets of experiments that the influence of mineral matter upon the caking properties of coal can be calculated provided the values of the constants in the derived equation are determined. It is, however, noted that the equation has been obtained by mixing mineral matter to coal and then noting the decrease in the dilatation. This means it is not possible to arrive at the same degree of thorough and intimate mixing as in naturally occurring coal. The bulk density of coal-sand mixtures can be taken to be an index of mixing and contact. It has been found experimentally that with 20 per cent sand a difference in bulk density of 28 per cent will bring about a difference in decrease of dilatation of 4·5 per cent. The difference in the bulk density of the coal pencil used for dilatation and that of the specific gravity of pure coal is of the order of 12 to 15 per cent which is, therefore, likely to bring about much less error. Experiments have shown that the degree of mixing does not much influence the action of mineral matter. This is because mineral matter is found to

TABLE 7—DILATATION OF COAL AND IRON MINERAL MIXTURES

Mineral content of the mixture, wt %			2·5	5·0	10
Av. wt of the coal pencil, g.			2·87	2·92	2·98
Mineral	Particle size/mm.	Sp. surface sq. cm./g.	Dilatation	Dilatation	Dilatation
Limonite D_0=86·5% (D_0=Dil. of original coal)	0 2-0·3	83	76·0	72·5	58·5
	0·042-0·1	288	73·0	59·0	35·0
	0·035	618	66·0	49·0	8·0
	0·01	2160	44·5	1·0	..
	0·001	..	16·0	..	..
Siderite D_0=88%	0·2-0·3	63·5	..	79·0	74·0
	0·42-0·1	221	..	70·0	56·0
	0·026	635	73·0	60·0	27·5
	0·007	2368	49·0	14·0	..
Haematite D_0=88%	0·2-0·3	46·0	..	78·5	74·0
	0·042-0·1	160	..	69·0	55·5
	0·028	428	..	50·0	16·0
	0·012	1000	56·0	28·0	..
	0·0031	4000	37·0	..	..
Pyrites D_0=89%	0·1-0·2	74·5	..	83·0	73·0
	0·042-0·1	158·5	..	79·0	71·0
	0·021	566·0	79·0	69·0	50·0

The calculated values of the constants are:

Limonite	n=0·52	k=1·43
Pyrites	n=0·50	k=0·54
Siderite	n=0·64	k=0·63
Haematite	n=0·67	k=0·63
Sand	n=0·27	k=0·82

start acting from the time the coal becomes plastic and the mineral has no action upon the temperature of plasticity. Once the coal becomes plastic, more intimate mixing and contact between the mineral and the coal takes place and the effect of the original void space is minimized.

TABLE 8—COMPARISON OF THE CALCULATED AND MEASURED DECREASE OF DILATATION OF COAL BY THE ADDITION OF DIFFERENT MINERALS

MINERAL	AMOUNT OF MINERAL IN MIXTURE, wt %	PARTICLE SIZE OF THE MINERAL, mm.	DECREASE IN DILATATION, %	
			Calculated	Measured
Limonite	5	0·075	28	26
n=0·52	10	0·035	41	38·5
ln k=+0·36	5	0·010	79	85·5
	2·5	0·0015 (biggest particle)	132	70
Haematite	5	0·075	18	17
n=0·64	5	0·012	53	53
ln k=−0·46	5	0·028	31·5	36·5
Siderite	5	0·26	8·0	7·5
n=0·60	5	0·75	17	16·5
ln k=−0·40	10	0·026	60	60
	5	0·007	67	74
Pyrites	5	0·075	10·5	9
n=0·50	5	0·021	18·5	20
ln k=−0·62	10	0·021	37	39

TABLE 9—EFFECT OF MIXTURES OF MINERALS UPON THE DILATATION OF COAL

(Coal—Ruhr Coking Coal; Dilatation, 78%)

MINERAL PARTICLE SIZE	SAND $<3\mu$ wt fraction	ΔD	KAOLIN $<2{\cdot}5\mu$ wt fraction	ΔD	LIMONITE $<1{\cdot}5\ \mu$ wt fraction	ΔD	MIXTURES Decrease in dil. ΔD	
							Calculated	Measured
Mixture of 2 minerals	4	19·5	6	37	..	..	56·5	55
Mixture of 3 minerals	3	15·5	4·5	28	0·5	13	56·5	57

ΔD—the decrease in dilatation is taken from the figure.

TABLE 10—CALCULATION OF DILATATION AND COMPARISON OF CALCULATED DILATATION WITH ESTIMATED DILATATION FOR WASHED COALS

Coal		Ruhr gas coal II fraction* size > 1 mm.	Indian coals	
			Dishergarh	Loyabad
Ash content, %		9·1	12·3	16·4
Mineral content, %		9·8	13·3	17·7
Vol. matter (moisture and ash-free), %		33·8	42·7	26·0
Dilatation, %		39·0	42·0	43·0
Dilatation with mineral addition,	3%	..	..	27·0
1·35 μ	5%	24·0	21·0	..
8·5 μ	3%	..	..	33·0
	5%	30·0	35·0	..
Calculated constants: n		0·277	0·595	0·256
k		0·48	0·082	0·985

ESTIMATED DILATATION OF SPECIFIC GRAVITY FRACTIONS OF COALS

Coal	Sp. gr.	Ash content	Vol. matter	Dilatation
Loyabad coal	<1·30	1·6	36·8	375
	<1·38	7·2	26·0	155
	<1·40	9·5	26·3	76
	<1·47	10·75	25·5	74
	<1·50	11·3	..	68
	<1·47	34·64	28·0	nil
	1·38-1·47	16·56	23·8	nil
Dishergarh coal	<1·32	6·1	42·8	107
	<1·39	9·9	41·8	69
Ruhr-gas coal	<1·29	1·31	35·2	100
size > 1 mm.	<1·40	2·93	33·5	69

*Since the total coal has a very low ash content, the size fraction of this coal(> 1 mm.) having a higher ash content has been used.

Calculated dilatation lines have been shown in Figs. 10 and 11.

The effect of mineral upon the caking properties of coal will be mainly determined by kaolin and quartz because the other minerals which are more effective like limonite are rarely found in coal and amongst the iron minerals pyrites is most widely present. It will, therefore, be sufficient if the effect of total mineral is considered as equivalent to the effect of kaolin and sand, when other minerals are present in very small amount. If the decrease in dilatation of the given coal with the addition of kaolin and sand is estimated, then from the values of the constants k and n (in equation 3) the increase in dilatation of clean coal with reduced mineral matter content can be calculated. Table 10 gives the examples of calculation of dilatation of a

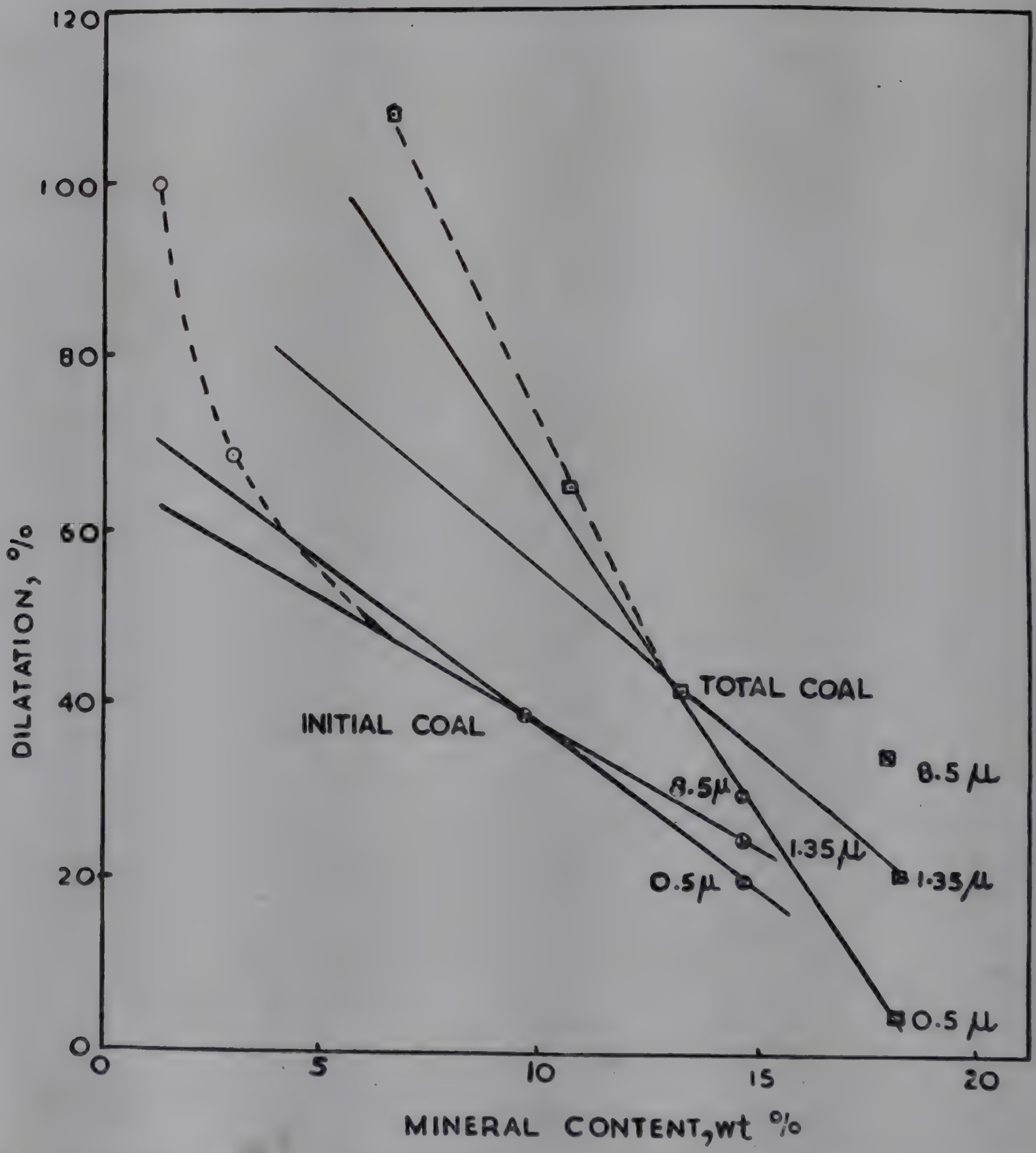

FIG. 10—COMPARISON OF CALCULATED AND MEASURED DILATATION OF TWO COALS: ⊡ Indian Coal Dishergarh, ⊙Ruhr gas coal fraction size > 1 mm. ⊗ ⊙Points for mixtures, —Calculated dilatation, ... Measured dilatation

washed coal. In Figs. 10 and 11 the calculated dilatation of the clean coal, considering the particle size of the mineral in coal to be $0{\cdot}5\mu$ and $1{\cdot}35\mu$, has been shown (the usual mineral size in coal is of the order of 1μ).

It may be noticed from Table 10 and Figs. 10 and 11 that as the specific gravity of the lighter fraction becomes very low, deviation between the calculated and measured dilatation takes place. The deviation is possibly due to some changes in petrographic composition, which can also be noted from the increase in the volatile matter content.

The Influence of Mineral Matter Upon the Roga-Index. The decrease in Roga-index with the addition of sand of different sizes and in different amounts is shown in Table 11 and Fig. 12.

In Table 11, since the Roga-index changes slightly on storage, the initial Roga-index is given in all cases. The effect of sand can be observed by comparison of the last two columns. The influence of other minerals is given in Table 12. Although the addition of sand decreases the Roga-index

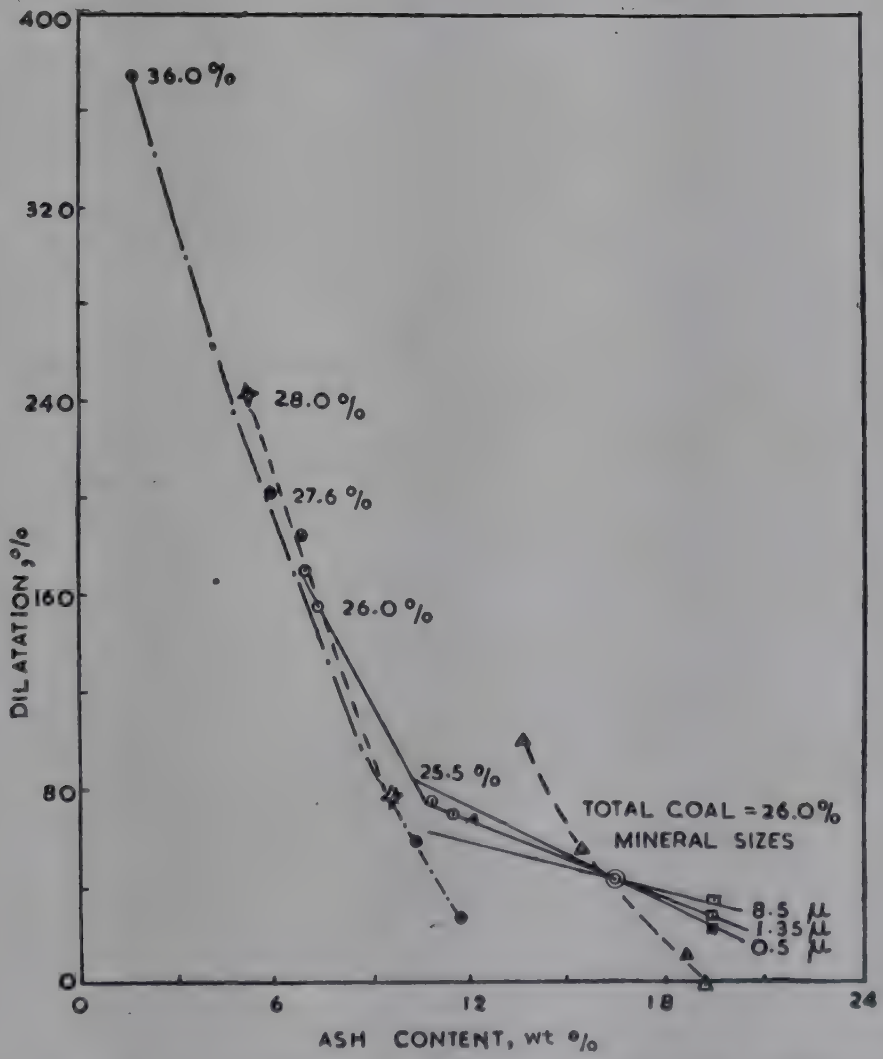

Fig. 11—Calculated and measured dilatation of coal fractions prepared by crushing and sieving and by gravity separation methods: △Different size fractions of original coal, ⊙Different sp. gr. fractions of original coal, ⊡ Coal, sand, kaolin calculated dilatation, ⊕ Different sp. gr. fraction of size fraction 0·1—0·5 mm. ⊗Mixture of two fractions; Numbers indicate volatile matter content

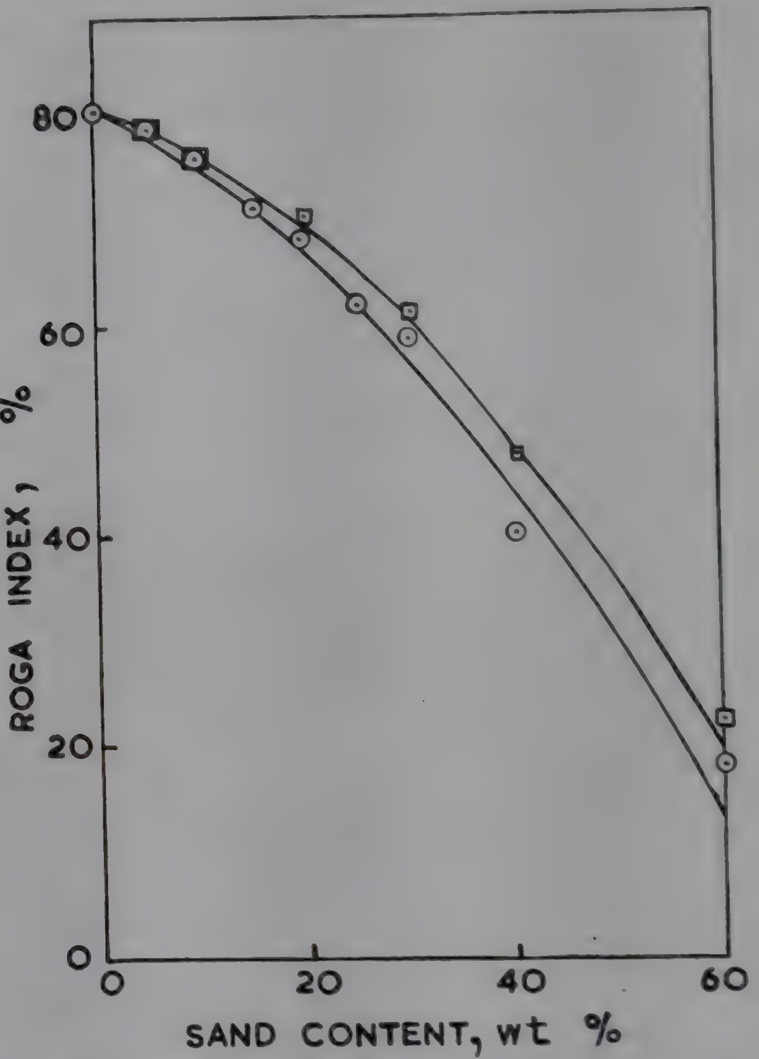

Fig. 12—Variations of Roga-index with addition of sand: ⊡ Coal without sand, ⊙ Coal with sand

TABLE 11—ROGA-INDEX OF COAL-SAND MIXTURES (RUHR COKING COAL)

Particle size of sand, mm.	Below 0·02	0·02 to 0·042	0·042 to 0·1	0·1 to 0·2	0·1 to 0·2 0·2 to 0·3	Roga-index	
						With sand	Without sand
Sand %							
0	77·0	77·0	77·0	80·5	77·0	77·0	80·5
5	74·3	75·3	75·0	79·5	76·3	76·5	79·3
10	72·6	73·8	70·4	76·5	73·6	73·7	76·0
15	..	..	..	71·5	..	..	..
20	68·5	69·7	68·4	68·5	68·5	68·5	71·0
25	..	..	..	62·5	..	..	..
30	..	..	..	59·0	..	..	..
40	..	..	..	40·0	..	..	..
60	..	..	..	18·0	..	..	..

TABLE 12—VARIATION OF ROGA-INDEX WITH THE ADDITION OF DIFFERENT MINERALS

MINERAL	PARTICLE SIZE, mm.	MINERAL ADDED, %	ROGA-INDEX %
Sand	0·042-0·1	5	79
	0·042-0·1	10	76·5
Calcite	0·042-0·1	5	78·3
	0·042-0·1	10	75·0
Siderite	0·042-0·1	5	76·0
Limonite	0·042-0·1	5	76·0
	0·042-0·1	10	73·3
Pyrite	0·042-0·1	10	77·0
Haematite	0·042-0·1	10	72·5
Sand	0·003	10	74·3
Kaolin	0·0025	10	74·0
Limonite	0·0015	10	34·2

TABLE 13—COMPARISON OF ROGA-INDEX OF DIFFERENT SPECIFIC GRAVITY FRACTIONS CALCULATED AND ACTUAL VALUES (RUHR GAS COAL)

Ash content	26%
Mineral content	28·1 (ash content × 1·08)
Dilatation	nil
Roga-index	21·5

Roga-index with mineral addition size 1·35μ

1%	Addition	18·7
2%	do	17·7
2·5%	do	17·4

Roga-index of sp. gr. fraction $\gamma < 1{\cdot}72$ with 10% mineral	21·5

ROGA-INDEX OF DIFFERENT SP. GR. FRACTIONS

SP. GR.	WT FRACTION, %	ASH CONTENT, %	MINERAL CONTENT, %	VOL. MATTER, %	DILATATION, %	RAGA-INDEX, %
<1·37	40·2	5·77	6·22	24·8	1·0	64·0
1·37-1·45	7·6	18·66	20·2	26·2	nil	20·0
<1·45	47·8	7·63	8·2	25·2	—10	60·5
<1·58	59·2	11·54	12·50	25·3	nil	52·0
1·45-1·58	11·4	28·16	30·60	28·0	nil	15·7
<1·72	69·3	14·60	15·80	26·0	nil	46·0
1·58-1·72	10·1	33·65	36·30	28·4	nil	nil
>1·72	30·7	52·90	57·00	36·8	nil	nil

the effect of particle size is not so pronounced except in the case of limonite whose presence is not very common in coal, as already mentioned. Thus the Roga-index will be mainly controlled by the quantity and not by the particle size of the mineral.

Calculation of Caking Properties of Washed Coal by Roga-index. It is found from a comparison of the dilatation results and the Roga-index results that the mineral matter has much less effect upon the Roga-index than dilatation and dilatation is a much more sensitive test and can be suitably used for systematic investigation. However, the relationship between dilatation and mineral matter can only be used for such coals which, due to their high initial ash content, give sufficient dilatation to calculate the value of the constants n and k. But when a coal due to unsuitable petrographic composition and high mineral matter content does not give any dilatation, the Roga-index is sufficiently high and the caking property can be correlated to Roga-index.

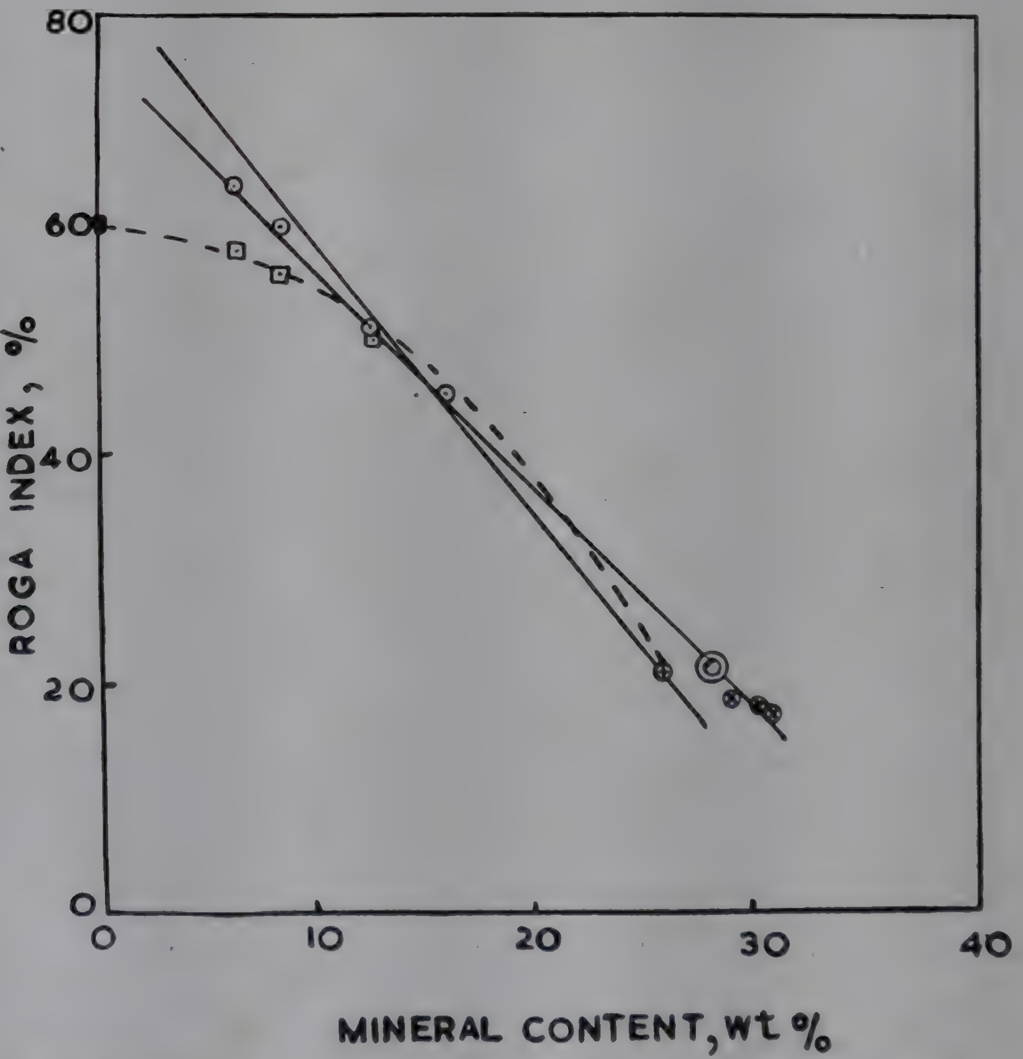

FIG. 13—CALCULATED AND EXPERIMENTAL ROGA-INDEX OF DIFFERENT SPECIFIC GRAVITY FRACTIONS: ◎Roga-index of original coal, ⊙Roga-index of specific gravity fractions, ⊗Roga-index of mixture with additional mineral, ⊕ Roga-index of fraction 1·72 with additional mineral, ⊡ Roga-index calculated

From Fig. 12 it can be observed that the curve for the variation of Roga-index and sand content is a parabolic one and follows the empirical relationship:

$$R = R_0 (1 - a g_s^2) \tag{4}$$

where R_0 = Roga-index of coal without addition of sand
R = Roga-index with addition of sand
g_s = Quantity of sand, gram per gram coal
a = constant (in this case equals 2)

The calculation or prediction of Roga-index of washed coal is possible (as in the case of dilatation) only when there is no change in petrographic composition during the beneficiation process. The Roga-index of high ash Ruhr coal which does not show any dilatation and those of the different specific gravity fractions are shown in Table 13 and Fig. 13. With the help of equation 4 the value of the constant 'a' is calculated and using this value the Roga-index of the different sp. gr. fractions with different mineral matter content obtained. In this particular case the Roga-index of the coal is rather low and as it may give rise to error, the sp. gr. fraction ($\gamma < 1{\cdot}72$) has been used to calculate the value of the constant a.

The calculation is as follows:

	Mineral content	Roga-index (R)
1. Experimentally found	0·158 g./g. coal	46%—R
2. ,, ,,	0·258 g./g. coal	21·5%—R_0
(with sand 10%)	(total in coal+sand)	

Now, $R = R_0 (1 - a g_s^2)$
calculated $a = 9{\cdot}6$
Roga-index without mineral, $R_0 = 60{\cdot}3$

From Fig. 13 it can be seen that the calculated and the experimental values are in agreement only up to a certain mineral matter content and there is a discrepancy when the mineral matter content is very low. The same observation was made in the case of dilatation.

It is, however, noticed from Fig. 13 that a linear relationship between the Roga-index and mineral matter content indicates better agreement between the calculated and the experimental values. No theoretical explanation can be given for this observation. It is possible that due to petrographic improvement of coal fraction the parabolic bend is not observed, and the coal gives a higher Roga-index and a straight relationship is obtained.

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Influence of Mineral Matter upon the Caking Properties of Coal : Part II*

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The effect of increase in mineral matter on dilatation by the addition of high ash fractions to low ash fractions (obtained from same coal by float and sink method) has been studied and compared with the results obtained by the addition of very fine mineral alone. If the petrographic composition of the two fractions is same, the decrease in dilatation is proportional to the increase in mineral matter. The results have been confirmed by petrographic analysis of different samples. Studies with some German and Indian coals showed that removal of heavier fractions up to a sp. gr. of about 1.47 does not cause any major change in petrographic composition. Hence the relationship between change in dilatation and mineral matter can be used to predict the changes in caking property of washed coal in large-scale practice.

It has been shown in Part I that the decrease in the caking properties of coal due to the presence of mineral matter can be calculated[1]. As petrographic composition and mineral matter will be simultaneously influencing the caking properties of coal, in actual cases when the samples are taken from different sources or when samples are prepared by gravity separation method, the derived relationship may not be sufficiently accurate. It has actually been found that the derived relationship is valid only to a limited extent of separation of high ash fraction from the low ash fraction. In general, apart from the adventitious mineral matter, the inherent mineral matter is so finely disseminated in coal as to make them completely inseparable.

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The usual method of float and sink or gravity separation separates coal into low and high-ash fractions and not distinctly into mineral matter and clean coal. The coal can be conceived, therefore, to be composed of a large number of fractions each having different ash content. When the effect of removal of a high-ash fraction from the total coal has to be envisaged for predicting the caking properties of the low-ash fraction, the petrographic composition of the coal in the high-ash fraction apart from the mineral matter content needs to be taken into account.

In the present work a sample of coal from Loyabad has been separated into different ash groups and the effect of mixing different high-ash fractions to the low-ash fractions have been investigated.

EXPERIMENTAL

The analysis of coal used is given in Table 1. The sample was crushed to below 3 mm. size and sieved into different size fractions. The properties of the different size fractions are also given in Table 1 and Fig. 1.

The sizes 1-3 mm., 0·5-1 mm. and 0·1-0·5 mm. have been separated into different sp. gr. fractions. The properties of these fractions are given in Table 2. The fraction obtained at sp. gr. <1·35 from size 0·5-1 mm. has been used as the low-ash constituent in the mixture, as it was obtained in sufficient quantity. High-ash fractions have been mixed in different proportions and the dilatation of the mixture found out. The results are

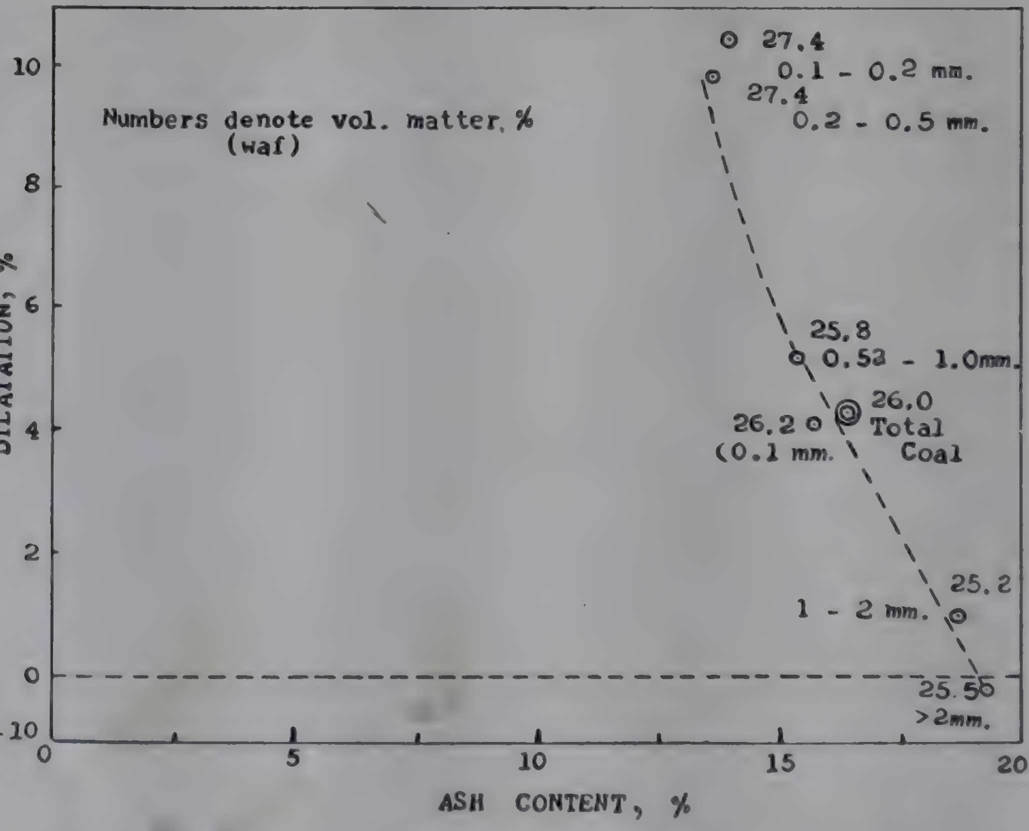

FIG. 1—DILATATION OF DIFFERENT SIZE FRACTIONS OF COAL

given in Table 3 and Figs. 2 and 3. Table 4 gives the decrease of dilatation for the increase of 1 per cent mineral matter content by the addition of high-ash coal fraction. The petrographic composition of different sp. gr. fractions of some of the size fractions of the coal are given along with other properties in Table 5.

RESULTS AND DISCUSSION

Table 1 and Fig. 1 show that during the process of crushing, coal is separated into different size fractions with different ash contents and caking properties. Table 2 shows that by gravity separation of the different size fractions (some size fractions are grouped together to have sufficient quantity for experimental purpose) the separation into different ash groups is more regular, but the caking property falls very sharply from a very high value to zero, although the increase in the mineral matter content is not so rapid. For an ash content of 12·5 per cent there is no dilatation (Fig. 4, size fraction 0·1-0·5 mm.). The reason is that the petrographic constituents Vitrain and

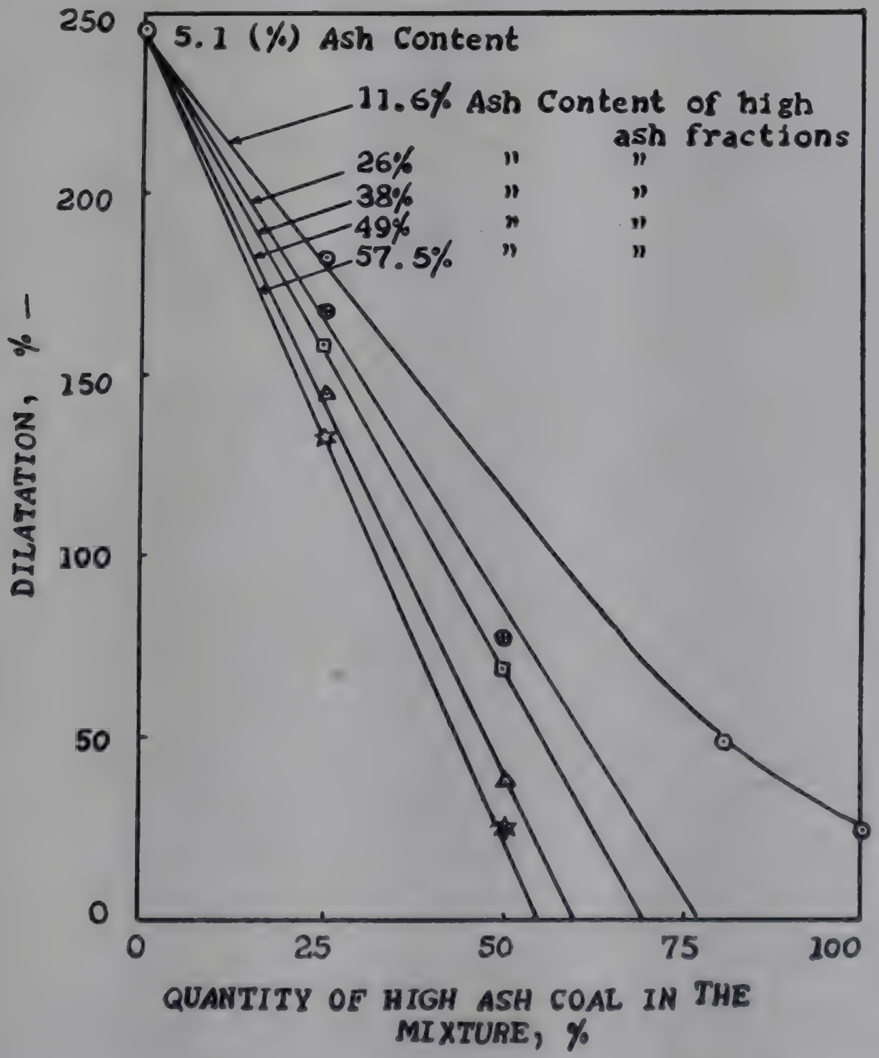

Fig. 2—Dilatation of mixtures of high ash and low ash fractions

TABLE 1—ANALYSIS AND PROPERTIES OF THE DIFFERENT SIZE FRACTIONS OF LOYABAD COAL

Size mm.	Wt fraction, %	Moisture content, %	Ash content, %	Volatile matter, %	Dilatation, %
Total coal	100·0	0·9	16·4	26·0	43
2-3	10·0	0·82	19·2	25·5	—2
1-2	30·0	0·85	18·6	25·2	10
0·5-1	24·5	0·85	15·4	25·8	52
0·2-0·5	20·0	0·88	13·6	27·4	98
0·1-0·2	7·5	0·77	14·1	27·4	105
Below 0·1	8·0	0·87	15·7	26·2	41

TABLE 2—DILATATION OF DIFFERENT SP. GR. FRACTIONS OF DIFFERENT SIZE FRACTIONS OF THE COAL

Sp. gr.	Ash content, %	Vol. matter, %	Dilatation %
	Fraction 1-3 mm.		
<1·4	9·5	26·3	76
1·4—1·6	21·1	25·4	nil
1·6—1·8	38·0	28·2	nil
1·8—2·0	49·0	35·2	nil
>2·0	57·5	40·0	nil
	Fraction 0·5-1·0 mm.		
<1·35	5·1	28·0	245
1·35—1·40	12·2	25·2	12
1·40—1·50	17·5	25·2	nil
1·50—1·60	26·0	26·4	nil
	Fraction 0·1-0·5 mm.		
<1·30	1·6	36·8	375
1·30—1·35	5·8	27·8	203
1·35—1·45	11·6	26·0	25
1·45—1·60	21·1	25·4	nil
>1·60	44·7	36·0	nil

TABLE 3—DILATATION OF MIXTURES OF HIGH ASH AND LOW ASH COAL FRACTIONS

QUANTITY OF HIGH ASH COAL IN MIXTURE, %	ASH CONTENT OF HIGH ASH COAL, %	ASH CONTENT OF MIXTURE, %	MINERAL CONTENT IN COAL			DILATATION
			In low ash coal, %	In high ash coal, %	Total, %	%
0	..	5·1	..	..	5·5	245
25	11·6	6·7	4·15	3·15	7·3	182
do	26·0	10·3	4·15	7·05	11·2	169
do	38·0	13·3	4·15	10·25	14·4	158
do	49·0	16·1	4·15	13·15	17·3	145
do	57·5	18·2	4·15	15·55	19·7	133
50	26·0	15·6	2·75	14.05	16·8	78
do	38·0	21·6	2·75	20·55	23·3	69
do	49·0	27·1	2·75	26·45	29·2	38
do	57·5	31·3	2·75	31·05	33·8	25
80	11·6	10·3	1·10	10·0	11·1	49
Mineral added			Mineral added, %	Mineral matter in coal, %	Total mineral matter, %	Dilatation
Kaolin ($<2·5\mu$), sand ($< 3\mu$) in the ratio of 60: 40			10	4·95	14·95	150
			20	4·40	24·40	50

TABLE 4—DECREASE IN DILATATION FOR THE INCREASE OF 1 PER CENT MINERAL MATTER BY THE ADDITION OF DIFFERENT HIGH ASH FRACTIONS

SP. GR. OF THE FRACTION	ASH CONTENT, %	MINERAL MATTER CONTENT, %	DECREASE IN DILATATION PER 1% INCREASE OF MINERAL
1·35-1·45	11·6	12·5	—35·0
1·50-1·60	26·0	28·1	—15·0
1·60-1·80	38·0	41·0	—10·0
1·80-2·00	49·0	52·9	— 8·6
>2·00	57·5	62·1	— 7·7
Sand + kaolin	..	..	—10·3

TABLE 5—PETROGRAPHIC COMPOSITION, ASH, VOLATILE MATTER CONTENT AND DILATATION OF THE DIFFERENT SIZE AND SP. GR. FRACTIONS OF LOYABAD COAL

	TOTAL COAL	SEPARATION ACCORDING TO SIZE, mm.					SEPARATION ACCORDING TO SP. GR.					
	1-3 mm.	0·1	0·1-0·2	0·2-0·5	0·5-1·0	1·0-2·0	<1·38	<1·47	1·38-1·47	>1·47	1·8-2·0	<1·30
Ash content, %	16·4	15·7	14·1	13·6	15·4	18·6	7·2	10·8	16·6	34·6	49·0	1·6
Volatile matter, %	26·0	26·2	27·4	27·4	25·8	25·2	26·0	25·5	23·8	28·0	35·2	36·8
Dilatation, %	43	42	105	98	52	10	155	74	0	0	0	375
Vitrinite vol., %	53	72	64	60	57	54	71	59	38	42	37	97
Exinite vol., %	5	2	6	7	3	3	6	5	6	2	1	2
Inertinite vol., %	32	23	23	25	32	33	19	30	46	33	18	1
Mineral vol., %	10	3	7	8	8	10	4	6	10	23	44	..

The petrographic analysis was kindly done by the Forschungsinstitute of Bergbauverein, Essen.

Clarain which possess the caking property have a sp. gr. of about 1·3, provided they are not mixed with minerals[1]. The higher sp. gr. fractions contain durain and more mineral matter.

Table 3 and Figs. 2 and 3 indicate that the decrease in dilatation is directly proportional to the quantity of high-ash coal added and that it increases with the rise of ash content in the high-ash coal. It has been found by van Krevelan[2] that the dilatation of a mixture of two coals is additive when the percentage of volatile matter and the softening point are almost the same or when the quantity of one of the coals is extremely small. The results of Table 3 are obtained with coals with different volatile matter contents. From Figs. 2 and 3 it can be seen that the dilatation curves of a mixture of two fractions are different from those of another mixture and the curves are automatically serially arranged according to the ash content of the high-ash fraction. When the two component coals are of the same petrographic composition, the effect will be only that of the mineral matter alone; but when the petrographic composition of high-ash fraction is such that it has no caking property, then the effect of this coal will be like the

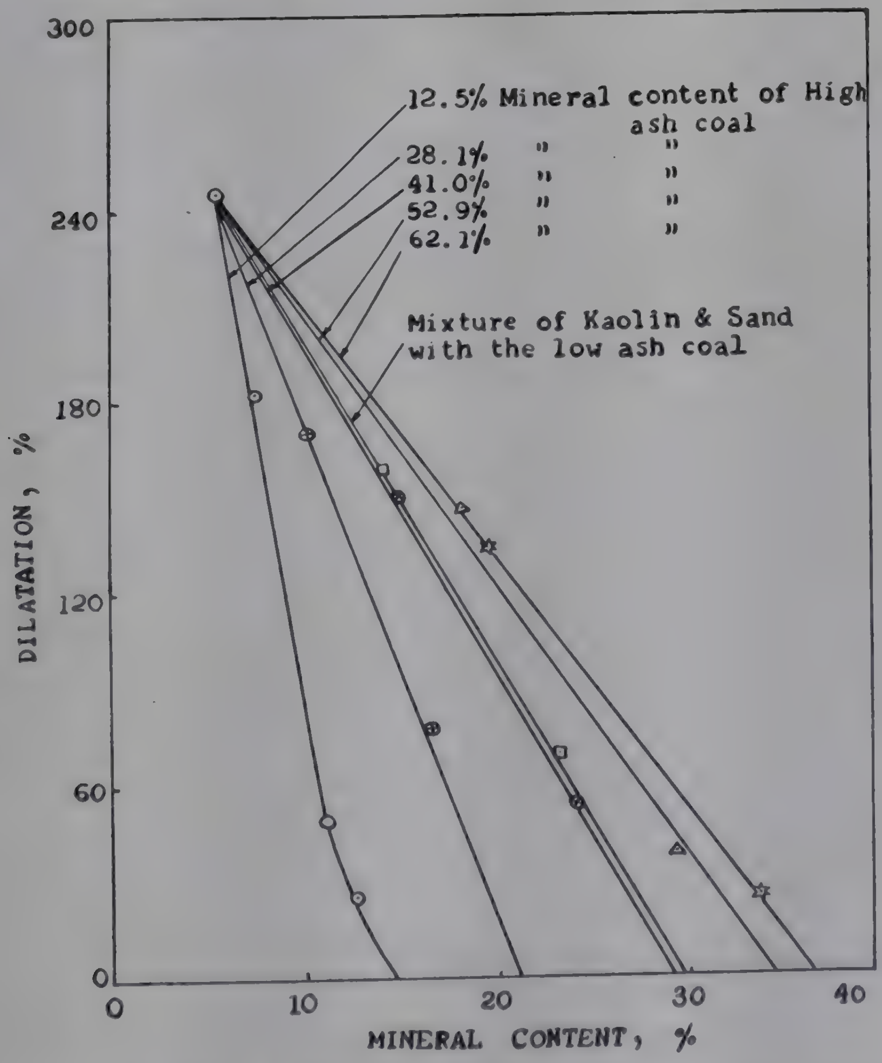

FIG. 3—DILATATION OF MIXTURES OF HIGH ASH AND LOW ASH FRACTIONS

addition of inert matter. The inert coal, depending upon the petrographic composition, may also differ in its behaviour in a mixture with other coking coal[3] so that each fraction may have a completely different effect upon the caking properties of mixture. Therefore in mixtures of high and low-ash coals, the effect is that of the mineral matter (which is more or less constant per unit mineral matter) and that of the inert constituent of the high-ash coal, the total effect being sum of these two. The addition of a mixture of kaolin + sand decreases the dilatation to the same extent as the coal having 38 per cent ash (when calculated on the basis of mineral matter content). Earlier it has been stated that the effect of addition of mineral matter (in this case sand + kaolin) is nearly the same as that of minerals present in coal[1]. It follows that the low ash coal and the high ash coal (having ash content of 38 per cent) have almost similar petrographic composition. The volatile matter content of the two fractions is almost the same.

From Table 4 it is seen that the decrease in dilatation per gram of addition of high-ash coal varies with the volatile matter content of the high-ash coal. With fractions containing less volatile matter the decrease per gram

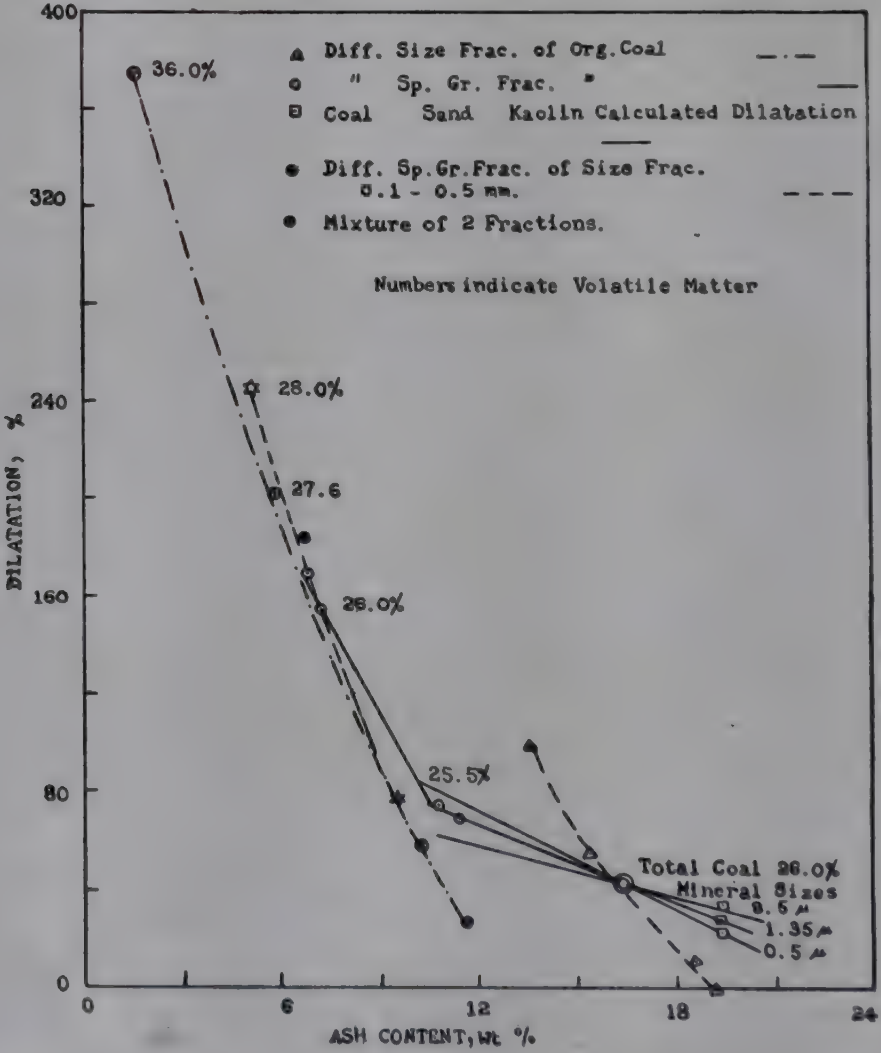

FIG. 4—CALCULATED AND MEASURED DILATATION OF COAL FRACTIONS PREPARED BY CRUSHING AND SIEVING, AND BY GRAVITY SEPARATION METHOD

is more and with those containing higher volatile matter the decrease per gram is less than that of sand + kaolin. When the volatile matter contents of the two component coals are the same, then the decrease per gram is the same as that of sand + kaolin.

The different results obtained for the beneficiation of coal and for the mixture of two coals can be qualitatively explained by means of petrographic analysis and from the content of inertinite (Table 5).

In the separation according to size, although much difference is noticed in dilatation, the ash content is not much different. The petrographic analysis shows that the inert coal content of bigger sizes is more than that in the smaller size and so they give lower dilatation.

In the fraction sp. gr. $<1{\cdot}38$ the inertinite content is less than in the original coal and in the fraction sp. gr. $<1{\cdot}47$ it is same as that of the original coal. The result is therefore that fractions of sp. gr. $<1{\cdot}38$ always show higher dilatation than can be expected from the removal of mineral matter alone, and the fraction of sp. gr. $<1{\cdot}47$ gives dilatation as expected from the mineral matter content.

It is found that in the fraction of sp. gr. 1·8 to 2·0 the inertinite content is less than the fraction of sp. gr. 1·38 to 1·47. In the mixture of these fractions with the low ash fraction, therefore, there is a greater decrease in dilatation in the second case than in the former and the effect is not due to mineral matter alone but also due to increase in inertinite content of the mixture.

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DISCUSSION

Shri S. Sarkar: In our studies on the influence of inerts on the dilatometric properties of coal [*J. sci. industr. Res.,* **17B** (1958), 127], we found an initial increase in the dilatation on the addition of mineral matter with a certain coal from Jharia. The authors have observed a decrease in dilatation by the addition of mineral matter. Could Dr Sen clarify this point?

Dr P. Sen: (written reply). The type of coal mentioned by Shri Sarkar may belong to perplastic or fluido-plastic group in which case the viscous strength of the fluid coal is not sufficient to push the plunger up. With the addition of mineral matter the fluidity decreases and the plunger can be pushed up. This leads to an increase in dilatation by the incorporation of inert matter; when the inert matter exceeds a certain limit, there is again a decrease in dilatation.

The experiment in this case should be conducted with a very light plunger in order that the coal may get full scope to expand without any physical resistance caused by the weight of plunger. Under these conditions anomalies may not be noticed. Usually the coke manufacturers are not to deal with such types of coal but with ortho- or para-plastic coals. These coals do not show any anomalies.

Studies in Vidarbha Coals: Part I—Preliminary Studies in Properties of Coals

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Wardha valley coals with their high ash and high moisture contents can be included in the group of low rank coals and they are absolutely noncoking. Washability tests showed that these are difficult to wash with considerably poor enrichment index. Enriched fractions were found to be poorer in caking properties. Petrographic examination of samples from Ballarpur and Sasti collieries proved their durain type characteristics. Tests on the degree of oxidation indicated their oxidation in seam.

Investigations were carried out to collect information on the Wardha valley coals and to study improved methods of their utilization with particular emphasis on coke and gas manufacture. The coals studied represent a large section of the deposits now being worked. Details regarding the procedure in obtaining the samples from the five mines—Ballarpur, Sasti, Hindustan Lalpeth, Majri and Ghughus are given in Appendix B.

The bulk samples from mines were subsampled by coning and quartering at every stage of size reduction. A portion of sample ground to pass through 7 mesh was dried at 50°C. to determine surface moisture. One half of this air-dried sample was used for float and sink tests while the other half was used for analysis after grinding to pass through 72 mesh B.S. sieve.

The proximate analysis of the coal samples from the five mines is given in Table 1. From the proximate analysis, the coals can be classified as low rank characterized by high moisture, high ash (except Lalpeth sample) and high V. M. contents and consequently low content of fixed carbon. They are non-caking and form a powder-like residue and are unsuitable for industrial coking.

FLOAT & SINK TESTS AND COAL WASHABILITY

The dried laboratory samples were subjected to float & sink tests using organic liquids to determine their washability characteristics, enrichment index and to concentrate the organics for reclassification. The specific gravities of liquids chosen were 1·5 and 1·8, since at sp. gr. 1·4 the recovery was insignificant and above 1·8 the ash content steeply increased.

The yields have been tabulated in Table 2 and their complete proximate analysis in Table 3. Table 4 shows the enrichment index of the coals calculated using the equation given in Appendix A.

TABLE 1—PROXIMATE ANALYSES OF WARDHA VALLEY COALS

	Name of colliery						
	Ballarpur		Ghughus		Sasti	H. Lal-peth	Majri
	1	2	1	2			
Proximate Analysis							
I. As received basis:							
Moisture, %							
(*a*) External	11·5	6·4	12·5	13·00	9·2	6·00	8·80
(*b*) Hygroscopic	5·3	5·8	7·3	5·8	6·8	12·4	8·3
Total	16·8	12·2	19·8	18·8	16·0	18·4	17·1
Ash, %	16·5	15·9	15·9	19·0	17·8	8·6	27·5
Volatile matter, %	32·3	33·0	33·3	33·7	30·2	27·8	23·8
Fixed carbon, %	45·9	45·3	43·5	41·5	45·2	51·2	40·4
Quality of coke	Non-caking	Non-caking	Non-caking	Non-caking	Non-caking	Non-caking	Non-caking
II. Dry and ash-free basis:							
Volatile matter, %	41·3	42·7	43·2	44·8	40·1	35·1	37·1

TABLE 2—YIELD OF GRAVITY FRACTIONS FROM WARDHA VALLEY COALS

Sp. gr. of the coal fraction	Ballarpur coals		Ghughus coals		Sasti coal	H. Lal-peth coal	Majri coal
	1	2	1	2			
Less than 1·5* (concentrate)	70·15	75·52	49·00	56·00	68·68	91·80	36·00
Between 1·5 and 1·8 (Intermediate products)	25·00	19·46	49·00	39·80	26·00	7·40	59·00
Less than 1·8**	95·15	94·98	98·00	95·80	94·68	99·20	95·00
More than 1·8 (waste rock residues)	4·85	5·02	2·00	4·20	5·32	0·80	5·00

*$CCl_4+C_6H_6$. ** CCl_4+CHBr_3.

TABLE 3—PROXIMATE ANALYSES OF GRAVITY FRACTIONS OBTAINED FROM WARDHA VALLEY COAL

	COAL SAMPLES AND THEIR FRACTIONS							
	Ballarpur coals				Ghughus coals			
	1		2		1		2	
	Fraction sp. gr. < 1·5	Fraction sp. gr. < 1·8	Fraction sp. gr. < 1·5	Fraction sp. gr. < 1·8	Fraction sp. gr. < 1·5	Fraction sp. gr. < 1·8	Fraction sp. gr. < 1·5	Fraction sp. gr. < 1·8
Yield, %	70·15	95·15	75·52	94·98	49·0	98·0	56·0	95·8
Proximate analysis								
As received basis, %								
Hygroscopic moisture	5·3	5·3	5·8	5·8	7·3	7·3	5·8	5·8
Ash	10·3	13·4	10·9	12·9	11·2	14·5	13·0	14·8
Volatile matter	31·3	32·9	35·3	33·7	30·6	31·2	32·3	32·1
Fixed carbon	53·1	48·4	48·0	47·6	40·9	47·0	48.9	47·3
Quality of coke	Non-caking		Non-caking		Non-caking		Non-caking	
Dry basis, %								
Ash	10·9	14·6	11·7	13·7	12·1	15·6	13·8	15·5
Volatile matter	33·0	34·7	36·4	35·8	33·0	33·6	34·3	34·3
Fixed carbon	56·1	50·7	51·9	50·5	54·9	50·6	51·9	50·2
Sulphur total	0·5	..	0·7	..	..	..	..	..
Dry and ash-free basis, %								
Volatile matter	40·6	40·9	41·2	41·9	37·6	39·8	39·8	40·6

(*Contd.*)

TABLE 3—*Contd.*

	COAL SAMPLES AND THEIR FRACTIONS					
	Sasti coals		Hindustan Lalpeth coals		Majri coals	
	Fraction sp. gr. < 1·5	Fraction sp. gr. < 1·8	Fraction sp. gr. < 1·5	Fraction sp. gr. < 1·8	Fraction sp. gr. < 1·5	Fraction sp. gr. < 1·8
Yield, %	68·68	94·68	91·80	99·20	36·00	95·00
Proximate analysis						
As received basis, %						
Hygroscopic moisture	6.8	6·8	12·1	12·1	8·3	8·3
Ash	10·4	14·1	7·0	8·3	11·0	17·9
Volatile matter	34·1	31·7	32·9	32·4	30·8	28·1
Fixed carbon	48·7	47·4	48·0	47·2	49·9	45·7
Quality of coke	Non-caking		Non-caking		Non-caking	
Dry basis, %						
Ash	11·2	15·1	8·0	9·3	12·0	19·6
Volatile matter	36·6	34·0	37·1	36·4	33·6	30·7
Fixed carbon	52·2	50·9	54·9	54·3	54·4	49·7
Sulphur total	0·6	..	..	..	..	..
Dry and ash-free basis, %						
Volatile matter	40·2	40·00	40·4	40·2	38·2	38·10

Easily enriched coals are those which under the enrichment test yield low ash concentrates (floats) without forming intermediate products; intermediate enrichment type coals are those which yield less than 10 per cent of an intermediate product; and lastly, difficultly enriched are those which yield more than 10 per cent intermediate products. All the coal samples (except H. Lalpeth) are therefore regarded as difficultly enriched coals.

SEPARATION AT A SP. GR. 1·4

Since the enrichment of all these coals was very low and the 1·5 fraction contained appreciable mineral matter, one of the coals, viz. Ballarpur-1 was further washed at 1·4 sp. gr. with a yield of 41·6 per cent (ash content 7·48 per cent). Table 5 compares the 1·4 fraction with 1 5 fraction of Ballarpur coal–1.

TABLE 4—ENRICHMENT INDEX OF WARDHA VALLEY COALS

	BALLARPUR COALS		GHUGHUS COALS		SASTI COAL	H.LALPETH COAL	MAJRI COAL
	1	2	1	2			
Enrichment index	7·80	6·83	4·47	4·45	5·56	11·56	3·46
No. of enrichment group*	7	8	10	10	9	5	9

*See Appendix A.

TABLE 5—COMPARISON OF PROPERTIES 1·4 SP. GR. AND 1·5 SP. GR. FRACTIONS OF BALLARPUR COAL NO. 1

	FRACTION OF SP. GR. $< 1·5$	FRACTION OF SP. GR. $< 1·4$
Yield	70·15	41·60
Proximate analysis, as received basis, %		
Hygroscopic moisture	5·3	5·3
Ash	10·3	7·5
Volatile matter	31·3	37·2
Fixed carbon	53·1	50·0
Quality of coke	Non-caking	Coherent
Dry and ash-free basis, %		
Volatile matter	40·6	42·6

Concentrates of sp. gr. 1·4 form in the crucible test a coherent residue while concentrates of sp. gr. 1·5 do not coke at all. This proves that concentrate of sp. gr. 1·4 has more substances capable to transfer into a plastic state, i.e. vitrains and spores while non-caking substances, fusain and minerals are more in the concentrate of sp. gr. 1·5 than in the concentrate of sp. gr. 1·4. It may therefore be concluded that sp. gr. of fusain varies within the range of sp. gr. 1·4 to 1·5.

VITRAIN IN SASTI COAL

Bright ingredients, viz. vitrain and partly clarain were manually separated from Sasti coal sample and coked in the crucible. It formed a weak cake. This tendency of the vitrain to form weakly coking mass may be due to either of the two possibilities, being low rank or due to oxidation in the seam due to oxidizing agencies.

Actual Rank of Coal Constituent Vitrain. A reappraisal of the high ash coals with particular reference to their volatile matter content may be made as below:

$$V_{M\,\text{actual}}^{\text{org.}} = \frac{A_{\text{raw}}^{\text{dry}} \times V_{M\,\text{enriched}}^{\text{dry}} - A_{\text{enriched}}^{\text{dry}} \times V_{M\,\text{raw}}^{\text{dry}}}{A_{\text{raw}}^{\text{dry}} - A_{\text{enriched}}^{\text{dry}}}$$

where $V_{M\,\text{actual}}^{\text{org.}}$ = % yield of V. M. from the proper organic mass of coals

$V_{M\,\text{raw}}^{\text{dry}}$ = % yield of V. M. from the dry mass of raw coal

$V_{M\,\text{enriched}}^{\text{dry}}$ = % yield of V. M. from the dry mass of enriched coal (sp. gr. $< 1{\cdot}8$)

$A_{\text{raw}}^{\text{dry}}$ = % ash content of dry mass of raw coal

$A_{\text{enriched}}^{\text{dry}}$ = % ash content of dry mass of enriched coal (sp. gr. $< 1{\cdot}8$)

From the formula

		$V_{M_{\text{actual}}}^{\text{org.}}$
Ballarpur coal	Sample 1	37·98%
,,	Sample 2	38·73%
,,	Sample 3	39·73%

Table 6 gives the proximate analysis of the vitrain separated from the Sasti coal sample.

Thus on the basis of the high values of $V_{M_{\text{actual}}}^{\text{org.}}$ and the high hygroscopic moisture (as shown in Table 6) it can be concluded that the coals are of very low rank. This has been further confirmed after determination of oxidation degree and petrographic examination.

OXIDATION DEGREE OF COAL SAMPLES

For determining the approximate oxidation degree of coals the Erdhmann method of alkali extraction and reprecipitation of the humic acids was followed. The regenerated humic precipitate after filtering, washing and drying was weighed, burnt and weighed again to deduct ash.

Since depth of coal seam would be one of the factors affecting the oxidation degree, samples from different depths of the same seam (Ballarpur) were subjected to the Erdhmann test, the results are tabulated in Table 7.

TABLE 6—PROXIMATE ANALYSES OF VITRAIN FROM SASTI COAL

	RAW SASTI COAL SAMPLE	VITRAIN OF SASTI COAL SAMPLE
As received basis, %		
Hygroscopic moisture	6·8	14·4
Ash	17·8	3·2
Volatile matter	30·2	34·3
Fixed carbon	45·2	48·1
Quality of coke	non-caking	
Dry and ash-free basis, %		
Volatile matter	40·1	41·9

Depth of coal seam is therefore an important factor in determining the oxidation degree of coal, although the number is not great enough to indicate a considerably great oxidation degree of this sample of vitrain.

PETROGRAPHIC INVESTIGATION

Petrographic study of the coals in question shows that these are of the durain type having thin layers of vitrain, clarain and fusain. A quantitative microscopic analysis in the reflected light and oil media (magnification 950) has been conducted (Table 8) with the concentrate of sp. gr. 1·5 particle size below 40 mesh, embedded in rosin in the form of pellets and polished.

Data in Table 8 show the petrographic similarity of all the coal samples as well as the petrographic heterogeneity of the individual samples and their low spores content. The vitrains are not helpful in caking because of very low rank and slight oxidation.

In view of the low rank and non-caking type of these coals and their poor washability characteristics, investigations on the following lines are suggested to make these coals suitable for coke and gas production:

(*i*) Binderless briquetting followed by carbonization;
(*ii*) Investigation on blending of the coals with suitable coking coals;
(*iii*) Briquetting using some bituminous binder like tar, pitch, etc. and carbonizing the briquettes.

TABLE 7—EFFECT OF DEPTH OF SEAM ON OXIDATION DEGREE

Coal from depth of	Amount of acid products
Ballarpur	0·51
coll. 265/270′	1·15
Sasti coll. 90′	3·32

TABLE 8—MICRO-COMPONENTS IN WARDHA VALLEY COALS

Micro-components	Percentage content in coals			
	Ballarpur		Sasti	Lalpeth
	1	2		
Vitrains	46 60	46 45	46·20	38·50
Fusains	30·25	29·90	32·00	39·00
Sporous substances	16·70	14·30	15·80	17·50
Mineral matter	6·45	9·35	6·00	5·00

The second part of the paper deals with the problem of binderless briquetting of the Vidarbha coals. These investigations were carried out at the Department of Chemical Technology, University of Bombay, at the instance of the Bombay Coke and Gas Committee.

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APPENDIX A

Enrichment Index T_b is calculated in the U.S.S.R. according to the equation:

$$T_b = \frac{P \times 100}{A \times B}$$

where

P = yield of floated fraction in the liquid of sp.gr. 1·5 (% of raw sample)
A = % ash content in coal fraction of sp.gr. $< 1{\cdot}5$
B = % yield of coal fraction of sp.gr. $< 1{\cdot}8$

GROUPING OF COALS ACCORDING TO THE VALUE OF THEIR ENRICHMENT INDEX, T_b

Enrichment Index T_b	No. of enrichment group	Name of enrichment group		Expected ash content of concentrate of the sp. gr. 1·5 (ash % on dry basis)
More than 20	I	High (easy)	1	Less than 5
20—16	II	,,	2	5—6
16—14	III	Intermediate	1	6—7
14—12	IV	,,	2	7—7·5
12—10	V	Low (difficult)	1	7·5—8
10—8	VI	,,	2	8—9
8—7	VII	,,	3	9—10
7—6	VIII	Very low	1	10—11
6—5	IX	,,	2	11—12
Less than 5	X	Extremely low		More than 12

APPENDIX B

Details of Coal Samples

1. Ballarpur Colliery—(*i*) Bottom section, 5 Rise, above 10 ft over 10 level in 15 level District. Depth 265 ft from the surface. (*ii*) Bottom section, 2 Dip, South between 2 and 4 levels. Depth 270 ft from the surface.
2. Sasti Colliery—Bottom section, 15 Dip, of main level off No. 2 pit, depth 90 ft from the surface.
3. Hindustan Lalpeth Colliery, Chanda, Incline section 22 Ls. off 36 Ds., 35 Ds.
4. Majri Colliery, Majri, Inclination 1 in. 5; direction South 62° west, 10 in. wide, height 12 ft.
5. Ghughus Colliery, Ghughus—(*i*) Robertson Incline—Meyo seam at 39 level North between 62 and 63 rise N. (*ii*) 2-3 pits at 39 dip off 2 level south, taken from bottom up to 11 ft height, approx. but chipping out the vertical surface throughout.

Briquetting and Carbonization and Briquetteless Carbonization of Ghughus and Majri Coals Blended with Caking Coals

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Results of blending Ghughus coal with Rakhicole coal and subsequent carbonization as such or after briquetting are described. Data regarding the water resistance of green briquettes prepared at room temperature and at 100°C. the crushing strength of briquettes carbonized at low and high temperatures and the water resistance of carbonized briquettes are included. Similar experiments with washed fractions of both coals are also reported. Addition of Jharia coals to Ghughus and Majri coals with or without Rakhicole coal and subsequent carbonization without briquetting showed that 60-70 per cent of Jharia coal was necessary to produce a hard and cellular coke.

Earlier work by Altekar *et al.* on the binderless briquetting of Ghughus coals indicated the possibility of obtaining a non-coky char of appreciable crushing strength. However, the wear resistance and cellular structure so characteristic of coke was absent.

The present paper describes the investigations undertaken to eliminate the briquetting operation and to obtain a coky mass by blending the Wardha valley coals with some coking coals.

By blending non-caking coals with strongly caking ones, an adherent mass can be obtained. The existence of caking coals in the Kanhan valley coalfields is reported in literature. Work done by the Central Fuel Research Institute (C.F.R.I.) on these coals showed Rakhicole to be having the most promising properties as a coking coal (Table 1).

Investigations carried out at the C.F.R.I. have shown that of all coals from Madhya Pradesh Rakhicole coal has the maximum fluidity temperature, caking index and swelling number, and gives a hard and porous coke on carbonization[1].

The results of the C.F.R.I. were confirmed by carbonizing the coal of sizes of —7, —36 and —72 mesh in steel boxes with a heating rate of 1·5° up to 600°C. and 3°/min. from 600 to 900°C. A hard coke of non-swelling but porous nature was obtained. The crushing strength of green briquettes of Rakhicole coal pressed at 32,200 psi. at room temperature was 1530 psi. On carbonization the briquettes prepared from —72 mesh size showed no swelling, whereas those from —7 mesh showed considerable swelling.

BLENDING OF THE GHUGHUS AND RAKHICOLE COALS

Both the coals were crushed to —7 mesh and dried at 60°C. for 15 min. before blending in a rotary mixer. The proportion of Ghughus coal in the blend was varied from 90 to 30 per cent by steps of 10 per cent. Each blend was carbonized without briquetting in a standard H.T.C. apparatus as also in steel boxes. It was observed that blends with up to 50 per cent of Rakhicole coal did not form lumps, whereas soft lumps were formed when

TABLE 1—PROXIMATE ANALYSIS OF RAKHICOLE COAL

		C.F.R.I. RESULTS (as received basis)	AUTHORS' RESULTS	
			As received basis	Dry basis
Moisture,	%	1·4	0·7	..
Ash,	%	21·5	17·9	18·0
Volatile matter,	%	26·9	30·8	31·0
Fixed carbon,	%	50·2	50·6	51·0
Colour of ash		..	brown	..

TABLE 2—CRUSHING STRENGTH OF GREEN BRIQUETTES FROM BLENDS

RAKHICOLE COAL IN THE BLEND, per cent	CRUSHING STRENGTH IN PSI. OF GREEN BRIQUETTES briquetting pressure					
	16,100 R.T.*	psi. 100°C.	32,200 R.T.*	psi. 100°C.	48,300 R.T.*	psi. 100°C.
10	724	3220	1771	3783	2415	4186
30	966	2495	2254	3564	2978	4025
40	966	2334	2093	3220	2415	3764
50	966	1932	2254	3000	2737	3630
70	1046	1610	2093	2737	3381	3542

* R.T.—Room Temperature.

the proportion exceeded 50 per cent. Blends of —72 mesh size also showed no marked adhesion on carbonization in the range of 10 to 70 per cent of Rakhicole coal.

CRUSHING STRENGTH AND WATER RESISTANCE OF GREEN BRIQUETTES

Blends of different mesh size and various proportions were prepared and briquetted under constant conditions of temperature and pressure. The greens were subjected to the crushing and the water stability tests. The results on crushing strength are given in Table 2.

The results indicate that the crushing strength of briquettes prepared at room temperature slightly increases with an increase in the proportion of Rakhicole coal, whereas that of the briquettes prepared at 100°C. decreases.

The greens were also subjected to the 24-hr water immersion test and then to crushing test after drying at 45°C. (Table 3). It was observed that all briquettes prepared at room temperature completely disintegrated irrespective of their composition or the briquetting pressure.

With increasing percentage of Rakhicole coal in the blend the water resistance of the green briquettes increases slightly for all pressures employed.

CRUSHING STRENGTH AND WATER RESISTANCE OF CARBONIZED BRIQUETTES

Briquettes were subjected to carbonization in Gray-King retorts at low and high temperatures. The chars were tested for crushing strength (Table 4).

Crushing strengths of the order of 6,000 psi. and above were observed in chars from blends of 50-50, the corresponding figures being more than 6,500 psi. for briquettes carbonized at higher temperature (Table 5).

The structure of the char was characteristic of the unfused, undigested particles of Ghughus coals embedded in or held by the bright cellular mass of Rakhicole coal which undergoes the plastic stage. All the chars had lesser volume than the original briquettes. Chars containing more than 40 per cent Rakhicole coal were free from cracks. They had good hard surfaces.

The crushing strength of the chars after 24 hr of immersion in water is given in Table 6. The loss of crushing strength due to immersion in water is much less for chars than for their original green briquettes. Even after a day's immersion, strengths of the order of 5,500 psi. were obtained for chars prepared under specific conditions.

The Gray-King assay (H.T.C.) results of blends of Rakhicole and Ghughus coals are given in Table 7.

TABLE 3—COMPARISON OF CRUSHING STRENGTHS: (i) BEFORE IMMERSION IN WATER AND (ii) AFTER IMMERSION IN WATER FOR 24 HR

Rakhicole coal in the briquettes, %	Crushing strength of briquettes in psi. when briquetted at 100°C.					
	Briquetting Pressure					
	16,100 psi.		32,200 psi.		48,300 psi.	
	Before immersion	After immersion	Before immersion	After immersion	Before immersion	After immersion
10	3220	+	3783	—	4186	—
30	2495	+	3564	805	4025	—
40	2334	242	3220	966	3764	1188
50	1932	—	3000	1044	3630	1207
70	1610	483	2737	1127	3542	1449

+ Sample disintegrated; — data not obtained.

TABLE 4—CRUSHING STRENGTH OF CHARS FROM L.T.C.

Blends containing Rakhicole coal, %	Briquetting pressure					
	16,100 psi.		32,200 psi.		48,300 psi.	
	R.T.*	100°C.	R.T.*	100°C.	R.T.*	100°C.
10	375	750	1000	3625	1750	3375
30	750	2750	1750	4875	2250	4375
40	1000	3125	2125	5300	3000	5250
50	1375	3375	2375	6125	3750	6375
70	2125	3750	2750	3150	3625	3625

* R. T.—Room Temperature.

TABLE 5—CRUSHING STRENGTH OF CHARS FROM H.T.C.

Blends containing Rakhicole coal, %	Briquetting pressure					
	16,000 psi.		32,200 psi.		48,300 psi.	
	R.T.*	100°C.	R.T.*	100°C.	R.T.*	100°C.
10	375	1625	1000	2875	2125	4125
30	750	2000	1250	4375	3000	6250
40	1000	2625	2500	6500	4250	5250
50	1550	3500	3000	6875	4875	5500
70	3000	4650	4250	6750	5625	5600

* R. T.—Room Temperature.

TABLE 6—EFFECT OF WATER ON CRUSHING STRENGTH OF CHARS

[Comparison of crushing strengths of chars: (i) before immersion and (ii) after immersion in water for 24 hr]

Rakhicoole coal in briquettes %	Crushing strength of chars in psi. Briquetting pressure and temp. 16,100 psi. R.T. F		16,100 psi. 100°C. F	S	32,200 psi. R.T. F	S	32,200 psi. 100°C. F	S	48,300 psi. R.T. F	S	48,300 psi. 100°C. F	S
		S										
10	375	250	1625	1475	1000	825	2875	..	2125	..	4125	3250
30	750	700	2000	1875	1250	990	4375	3625	3000	2634	6250	5012
50	1550	1225	3500	3350	3000	1975	6875	5725	4875	3737	5500	4868
70	3000	2650	4650	3425	4250	3350	6750	5702	5625	4803	5600	4875

F—Fresh; S—Soaked

TABLE 7—GRAY-KING ASSAY (H.T.C.) OF 50-50 BLENDS AND 30-70 BLENDS

Blend	50% Rakhicoole 50% Ghughus	70% Rakhicoole 30% Ghughus
Char	66·03 %	67·32 %
Tar and liquor	18·58 %	18·36 %
Ammonia	0·069%	0·061%
Gas at N.T.P.	24·9 l./100 g.	27·71 l./100 g.

TABLE 8—CRUSHING STRENGTH OF GREEN BRIQUETTES FROM PREHEATED GHUGHUS COAL AND RAW RAKHICOOLE COAL

Blends containing Rakhicoole coal, %	Crushing strength in psi. briquetted at 16,100 psi. R.T.	16,100 psi. 100°C.	32,200 psi. R.T.	32,200 psi. 100°C.	48,300 psi. R.T.	48,300 psi. 100°C.
30	..	..	563	1280	...	2173
50	350	..	—	.	.	..
70	322	966	—	2254	..	.

BLENDING OF PREHEATED GHUGHUS COAL AND RAW RAKHICOLE COAL

In this series of experiments Ghughus coal was preheated to 300°C. for 1/2 hr and cooled before blending it with Rakhicole coal. Crushing strengths of green briquettes and chars obtained at L.T.C. and H.T.C. are shown in Tables 8 and 9.

It became evident that the chars obtained from blends containing preheated Ghughus coals were poorer in strength and were softer.

BLENDING, BRIQUETTING AND CARBONIZATION OF WASHED FRACTIONS

The ash contents of Rakhicole as well as of Ghughus coals were a serious disadvantage and attempts were therefore made to process only the washed fractions of coals. Fractions lighter than 1·6 with higher contents of vitrain and clarain and lower content of mineral matter can be expected to give chars with better properties.

The proximate analyses of the washed fractions of the two coals are shown in Table 10.

TABLE 9—CRUSHING STRENGTH OF CHARS FROM L.T.C. AND H.T.C. OF BRIQUETTES FROM PREHEATED GHUGHUS COAL AND RAW RAKHICOLE COAL

Blends containing Rakhicole coal %	L.T.C.				H.T.C.			
	32,200 psi.		48,300 psi.		32,200 psi.		48,300 psi.	
	R.T.	100°C.	R.T.	100°C.	R.T.	100°C.	R.T.	100°C.
30	0	129	161	322	322	..	564	..
50	322	483	644	..	724	..	966	..
70	1449	..	1610	2415	2012	3220	2415	3864

TABLE 10—PROXIMATE ANALYSIS OF WASHED FRACTIONS OF RAKHICOLE AND GHUGHUS COALS

	Rakhicole coal		Ghughus coal	
	As received basis	Dry basis	As received basis	Dry basis
Moisture, %	1·0	..	7·3	..
Ash, %	12·4	12·5	11·0	11·9
Volatile matter, %	30·0	30·3	30·6	33·0
Fixed carbon, %	56·6	57·2	51·1	55·1

Blends of the two washed fractions were prepared with 30 to 70 per cent of Rakhicole content. The green briquettes had in general much lower crushing strength (Table 11).

There was a definite trend towards decreasing strength with the increase in the proportion of Rakhicole in the green briquettes.

The briquettes were carbonized in the Gray-King apparatus and the crushing strengths observed are given in Table 12. The results are remarkable, in that the variations in temperature and pressure have very marked effect on the crushing strength. Here increasing the proportion of Rakhicole raised the strength of char while it had lowered the strength of green briquette. The chars obtained from 50 per cent and 70 per cent Rakhicole blends were very hard and free from cracks. There was no cellular structure and no shrinkage on carbonization.

TABLE 11—CRUSHING STRENGTH OF GREEN BRIQUETTES FROM WASHED COALS

RAKHICOLE COAL IN BRIQUETTES, %	CRUSHING STRENGTH IN PSI. Briquetting pressure					
	16,100 psi.		32,200 psi.		48,300 psi.	
	R.T.	100°C.	R.T.	100°C.	R.T.	100°C.
10	402	1771	1046	2978	2254	3300
30	360	1368	966	2576	2093	2898
50	302	1288	901	2093	1851	2817
70	193	966	837	1932	1771	2730

TABLE 12—CRUSHING STRENGTH OF CHARS FROM BLENDS OF WASHED COALS

RAKHICOLE COAL, %	CRUSHING STRENGTH IN PSI.											
	L.T.C.						H.T.C.					
	Briquetting pressure											
	16,100 psi.		32,200 psi.		48,300 psi.		16,100 psi.		32,200 psi.		48,300 psi.	
	R.T.	100°C.	R.T.	100°C.	R.T.	100°C.	R.T.	100°C.	R.T.	100°C.	R.T.	100°C.
10	..	375	110	1250	875	2075	175	750	425	1400	725	2150
30	125	1050	550	1325	1150	..	..	1325	625	1750	1150	3075
50	175	1175	875	1875	1325	2275	375	1875	750	2500	1750	5025
70	225	1325	950	2475	1400	2475	525	2100	1050	4350	2000	6000

The proximate analyses of the green blend of —1·5 fraction (70 per cent Rakhicole coal) and the char obtained therefrom are given in Table 13.

The chars from this series were found to be very hygroscopic. The freshly prepared chars were free from moisture but even in comparatively dry months, they absorbed moisture as follows: 5·7 per cent in 48 hr, 6·86 per cent in 72 hr, and 6·89 per cent in 96 hr.

This could probably be due to the adsorbed zinc chloride from the heavy solution during float and sink tests.

The Gray-King H.T.C. assay of Rakhicole-Ghughus coals in 70-30 mix was as below:

Product	*Yield*/100g. *dry coal*
Char	69·5
Tar and liquor	22·20
Ammonia	0·0315
Gas at N.T.P.	19·5 l.

TABLE 13—PROXIMATE ANALYSES OF GREEN BLEND AND CHAR OF 70 PER CENT RAKHICOLE COAL WITH 30 PER CENT GHUGHUS COAL
(as received basis)

	GREEN	CHAR (H.T.C.)
Moisture, %	1·4	5·2
Ash, %	13·0	16·2
V.M., %	34·5	6·3
F.C., %	51·1	72·3

TABLE 14—CRUSHING STRENGTH OF CHARS AFTER 24 HR OF WATER IMMERSION

RAKHICOLE COAL (sp. gr. 1·5) IN BRIQUETTES, %	CRUSHING STRENGTH IN PSI. BRIQUETTED AT 100°C.		
	16,100 psi.	32,200 psi.	48,300 psi.
10	425	1100	1975
30	1150	1590	3000
50	1740	2400	4625
70	2025	4275	5850

TABLE 15—BLENDING AND CARBONIZATION OF GHUGHUS AND JHARIA COALS

S. No.	COMPOSITION OF THE BLENDS				QUALITY OF CARBONIZED PRODUCT							
	Ghughus coal	Rakhicole coal	Jharia coal	Hard pitch	Impact resistance	Porosity	Friability	Soiling hand	Hardness	Coke structure	Breaking strength	General remarks
1.	100	..	..	..	..	..	..	..	..	No	..	Completely non-caking
2.	70	30	..	..	No	..	f	..	s	..	..	Unsuitable
3.	50	50	..	..	..	high	..	..	s	..	poor	a; b
4.	30	70	..	..	same as above							
5.	40	60	..	..	No	..	..	yes	s	No	poor	Unsuitable
6.	50	40	..	10	..	high	f	yes	s	..	..	b; a
7.	30	60	..	10	same as above							
8.	33·3	33·3	33·3	..	No	high	f	..	s	..	..	b; c
9.	40	10	50	..	No	high	f	yes	..	..	..	a; c
10.	30	20	50	..	No	high	..	No	h	cellular	..	b; d
*11.	30	20	50	..	..	poor	..	yes	s	..	poor	Unsatisfactory
12.	70	..	30	..	poor	..	..	..	s	..	..	c
13.	50	..	50	..	poor	high	..	yes	h	cellular	..	Better than any blend from Ghugus and Rakhicole coals
14.	40	..	60	..	insufficient	poor	..	No	h	..	good	d
*15.	40	..	60	..	..	..	..	yes	Not hard	..	..	c; not satisfactory

(*Contd.*)

TABLE 15—*Contd.*

S. No.	COMPOSITION OF THE BLENDS				QUALITY OF CARBONIZED PRODUCT							
	Ghughus coal	Rakhicole coal	Jharia coal	Hard pitch	Impact resistance	Porosity	Friability	Soiling hand	Hardness	Coke structure	Breaking strength	General remarks
16.	30	..	70	..	high	poor	..	..	h	cellular	high	d; satisfactory
*17.	30	..	70	..	..	Nil	..	..	h	cellular	..	Not as good as above
18.	40	..	50	10	..	high	..	No	h	cellular	..	Not as good as (16)
19.	40	..	40	20	..	high	..	No	h	..	..	Shining & lustrous, not very satisfactory
20.	90	..	..	10	..	..	..	..	..	..	..	No lump formation; unsatisfactory
21.	80	..	..	20	..	..	..	..	..	..	..	Same as above

f—friable; s—soft; h—hard
a—Ghughus coal particles not digested by Rakhicole coke
b—Rakhicole coke forms thin-walled globules
c—Jharia coal forms a good hard coke
d—Ghughus coal particles digested by Jharia coal
*Blends from—72 mesh sized material.

TABLE 15A—BLENDING AND CARBONIZATION OF MAJRI AND JHARIA COALS

S. No.	COMPOSITION OF THE BLENDS					QUALITY OF CARBONIZED PRODUCT							REMARKS
	Majri coal	Jharia coal	Rakhicole coal	Hard pitch	Ghughus coal	Porosity	Hardness	Soiling hand	Friability	Impact resistance	Breaking strength	Structure	
1.	100	..	..	..	..	..	..	..	..	..	..	..	Non-caking coal
2.	50	50	..	..	..	p	h	No	..	..	good	..	a

(*Contd.*)

TABLE 15A—*Contd.*

S. No.	COMPOSITION OF THE BLENDS					QUALITY OF CARBONIZED PRODUCT							REMARKS
	Majri coal	Jharia coal	Rakhi-cole coal	Hard pitch	Ghughus coal	Porosity	Hardness	Soiling hand	Friability	Impact resistance	Breaking strength	Structure	
3.	50	40	..	10	..	p	not very hard	..	..	..	..	..	a
4.	40	60	..	..	..	..	h	No	..	..	..	..	a
5.	40	50	10	..	..	p	sufficient	No	..	..	good	..	b; c
6.	40	50	..	10	..	p	h	No	..	..	good	..	d; good coke
7.	40	40	20	..	..	p	s	No	..	..	good	..	b; c
8.	40	40	..	..	20	p	s	Yes	..	..	..	..	a; c
9.	35	60	..	5	..	..	h	No	..	..	good	compact	d; good coke
10.	35	50	10	5	..	..	not very hard	..	..	..	..	..	a; e; not as good as (9)
11.	30	70	..	..	..	..	h	No	..	..	good	compact cellular	d
*12.	30	70	..	..	..	p	h	No	..	..	good	..	d; best coke
13.	30 (−72 mesh)	70 (−7 mesh)	..	..	..	Non-porous	not very hard	No	..	..	poor	..	..
14.	30	70	..	..	..	..	..	..	..	..	..	..	d; good coke
15.	30	60	10	..	..	less porous	h	No	..	good	..	..	a
16.	30	60	..	10	..	not very porous	h	No	..	good	good	..	d; better than (15) and comparable (to 12)

(Contd.)

TABLE 15A—*Contd.*

S. No.	COMPOSITION OF THE BLENDS					QUALITY OF CARBONIZED PRODUCT							REMARKS
	Majri coal	Jharia coal	Rakhi-cole coal	Hard pitch	Ghughus coal	Porosity	Hardness	Soiling hand	Friability	Impact resistance	Breaking strength	Structure	
17.	30	50	20	..	..	non-porous	not very hard	..	..	good	..	..	a; e
18.	30	50	10	10	..	p	s	..	..	..	..	..	a
19.	30	50	10	..	10	sightly porous	h	No	..	good	good	..	Better than (18)
20.	30	40	10	..	20	not very porous	..	..	..	..	..	..	e; c
21.	30	40	..	10	20	..	s	No	..	..	..	..	a; c
22.	30	40	..	..	30	slightly porous	s	..	..	..	..	..	a; c
23.	20	50	10	..	20	p	not very hard	No	..	..	..	..	a

h—hard; s—soft; p—porous
a—Majri coal particles not properly digested or embedded
b—Majri coke gets dislodged on dropping
c—Not satisfactory
d—Majri coal well digested
e—Rakhicole coal forms shining globules
*Blends from —72 mesh sized material.

WATER RESISTANCE OF GREEN BRIQUETTES AND CHARS

The briquettes were subjected to water immersion tests before and after carbonization. As in earlier experiments all briquettes prepared at room temperatures were completely disintegrated on immersion. Those prepared at 100°C. also suffered a loss of strength as in earlier cases. Strength of the chars were little affected as recorded in Table 14.

It is to be noted that the higher the proportion of Rakhicole coal in the blend the better was the water resistance of the green briquettes as well as of the chars obtained.

BLENDING WITH JHARIA COKING COAL

In this series of experiments it was first established that the caking coal of No. 14 seam Jharia formed an adherent mass when blended and carbonized loose with Ghughus and Majri coals. The need for briquetting was thus definitely eliminated.

Blending of the various ingredients at various sizes and proportions were tried. The blends were weighed (200 g.) and charged in steel boxes and heated in a muffle furnace at 900°C. for 18 hr. The boxes were then taken out and quenched in water. The coke was examined qualitatively and observations recorded as in Tables 15 and 15A.

It may be summarized on the basis of these tables that the role of Jharia coal in forming a hard coky mass was much more significant than that of Rakhicole coal. The best results were obtained when the proportion of Jharia coal was 70 per cent or more; with lesser amounts, the undigested Ghughus coal particles were loosely held in the coke.

The tests reported in these tables are to be taken only as weeding-out operations to find out the best blends that could be tried out on larger scales. It was originally intended to follow these tests with larger-scale ones, but due to non-availability of large quantities of Jharia coal this could not be done.

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Assessment of Low Temperature Carbonization Products from Petrographic Composition of Coals

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From a simple knowledge of maceral composition of coals it is possible to predict tar yields on low temperature carbonization. A linear relationship has been found between tar yields and perhydrous constituents. It follows as a corollary that the maceral inertinites have a reverse relationship with tar yield. In addition, char yield is found to be broadly proportional to the increase in inertinite content. These studies have been mainly confined to low and medium rank coals.

A knowledge of the quantity and quality of the products of low temperature carbonization (l.t.c) is an essential prerequisite for planning any industry based on l.t.c. of coal. Primary indications for the carbonizing potentialities of coals at low temperature are usually obtained in the laboratory from the Gray-King low temperature (600°C.) assay. Various attempts have been made to correlate and interpret yields of l.t.c. products from laboratory assay with those obtained in actual plant practice[1]. Correlations have also been attempted and formulae established between the chemical analyses of coals and yields of l.t.c. products, primarily with a view to predicting yields of l.t.c. products (tar in particular)[1,2,3].

Wide discrepancies may often be observed in such correlations, difficult to account for on chemical grounds alone. Investigations suggest that amongst various reasons; the petrographic non-homogeneity of coals may usually give rise to such discrepancies, particularly in coals of low to medium ranks. The results obtained, therefore, are either inaccurate or only approximate depending on the ranges and types of coals considered mainly because it may not be possible to predict the properties of a mixture from its analysis unless the properties of the constituents (macerals) are taken into consideration.

It has been known that tar yields are directly related to volatile matter and hydrogen content in coals. Exceptions are not infrequent. Coals with nearly the same volatile matter and hydrogen contents may yield different quantities of tar (Table 1). Such anomalous relation has often been observed specially in coals of low rank occurring in Andhra, Maharashtra, Orissa and Madhya Pradesh coalfields and may be explained if coal is viewed from petrological angle.

Megascopically, coal is composed of rock types such as vitrain, durain, etc. besides mineral matter. Each of these in turn is composed of varying

TABLE 1—TAR YIELD WITH RESPECT TO VOLATILE MATTER AND HYDROGEN CONTENT OF COALS

SL No.	DETAILS OF SAMPLE	VOLATILE MATTER, % (unit coal)	HYDROGEN, % (unit coal)	L.T. TAR YIELD, % (unit coal)
1. a.	Charcha coal, Sohagpur C.F.	32·5	4·82	11·5
b.	Ghordewa coal, Korba C.F.	32·3	4·78	9·0
2. a.	Ghorghella Nalla coal, Chirimiri C.F.	34·8	4·97	10·9
b.	Pure Chirimiri coal, Chirimiri C.F.	34·5	4·85	12·8
3.	Ghordewa coal, Korba C.F.	33·8 34·4	4·92 4·93	10·3 11·8
4. a.	Upkanalla coal, Bisrampur C.F.	35·3	4·65	8·4
b.	New Chirimiri coal, Chirimiri C.F.	35·4	4·65	11·8
5. a.	Pure Chirimiri coal, Chirimiri C.F.	36·1	5·07	14·4
b.	Upper Rajgamar coal, Korba C.F.	37·4	5·10	11·9
6. a.	Five foot seam coal, Chirimiri C.F.	39·4	5·48	18.3
b.	Monoharbahal coal, Raniganj C.F.	41·4	5·62	15·9
7. a.	Sonhat coal, Sohagpur C.F.	37·0	5·36	16·9
b.	Bijuri coal, Sohagpur C.F.	37·2	5·36	15·0
8. a.	Ponri Hill coal, Chirimiri C.F.	35·4	4·65	11·8
b.	Lower Ghordewa coal, Korba C.F.	35·1	4·68	9·5
9. a.	Ambara 4 & 5 Adit Mines coal, Pench Valley C.F.	42·1	5·09	15·3
b.	Lower Rajgamar coal, Korba C.F.	42·8	5·35	13·8
10. a.	Charcha coal, Sohagpur C.F.	39·5	5·19	15·0
b.	Kurasia Top seam coal, Chirimiri C.F.	39·5	5·28	13·5

proportions of macerals, namely, vitrinite, exinite, micrinite, selerotinite, semifusinite and fusinite. The last four are usually grouped together under the general term 'inertinite' for obvious reasons. The physical and chemical properties of each of these microscopically identifiable constituents (differing in their morphology) are different. Hence their presence in varying proportions should normally influence the overall physical and chemical behaviour of a coal; particularly so, when one or more of the constituents is present in very high or very low proportions.

An attempt has been made to correlate and interpret from their petrographic composition, the nature and yields of the main products of coal, when subjected to l.t.c. assay at 600°C. The study has been mainly confined to coals of low to medium ranks as are largely produced in these areas.

METHOD

Petrographic methods developed for the preparation of samples and quantitative analysis have been described elsewhere[4,5,6]. A representative sample of powdered coal is made into a pellet using a suitable plastic binder. Its surface is cut, ground and polished. Quantitative estimation of macerals is carried out with the help of an integrating stage using the reflected light technique with dry or preferably oil immersion lens.

The results of petrographic analysis are expressed on visible mineral-free basis (a new method of expression used by the authors) with a view to comparing with chemical data, expressed on the basis of pure coal substance. This is done by running over the mineral matter on an auxiliary stage fitted to the integrating device.

RESULTS AND DISCUSSION

The main products of l.t.c. assay have been determined with respect to yields of tar, coke and gas in the Gray-King apparatus. Based on the results of observations, it has been found possible to establish a relation between the tar yields and certain maceral contents of coal. From petrographic studies on the quantitative composition of coals in general and the percentages of vitrinite and exinite in particular, it is observed that, as the sum total of the latter two macerals increases, tar yields tend to increase for low to medium rank coals (Table 2). If these (expressed on visible mineral-free coal) are plotted against tar yields (unit coal basis) a very narrow band, is obtained suggesting a linear relationship and may be expressed by:

$$Y=2{\cdot}317+0{\cdot}158x_1 \qquad (1)$$

where Y=Tar yields % (unit coal) from Gray-King l.t.c. assay and

x_1=Vitrinite % + Exinite % (visible mineral-free).

Fig. 1 statistically explains the linear relationship, giving a high correlation coefficient of 0·91 for equation (1).

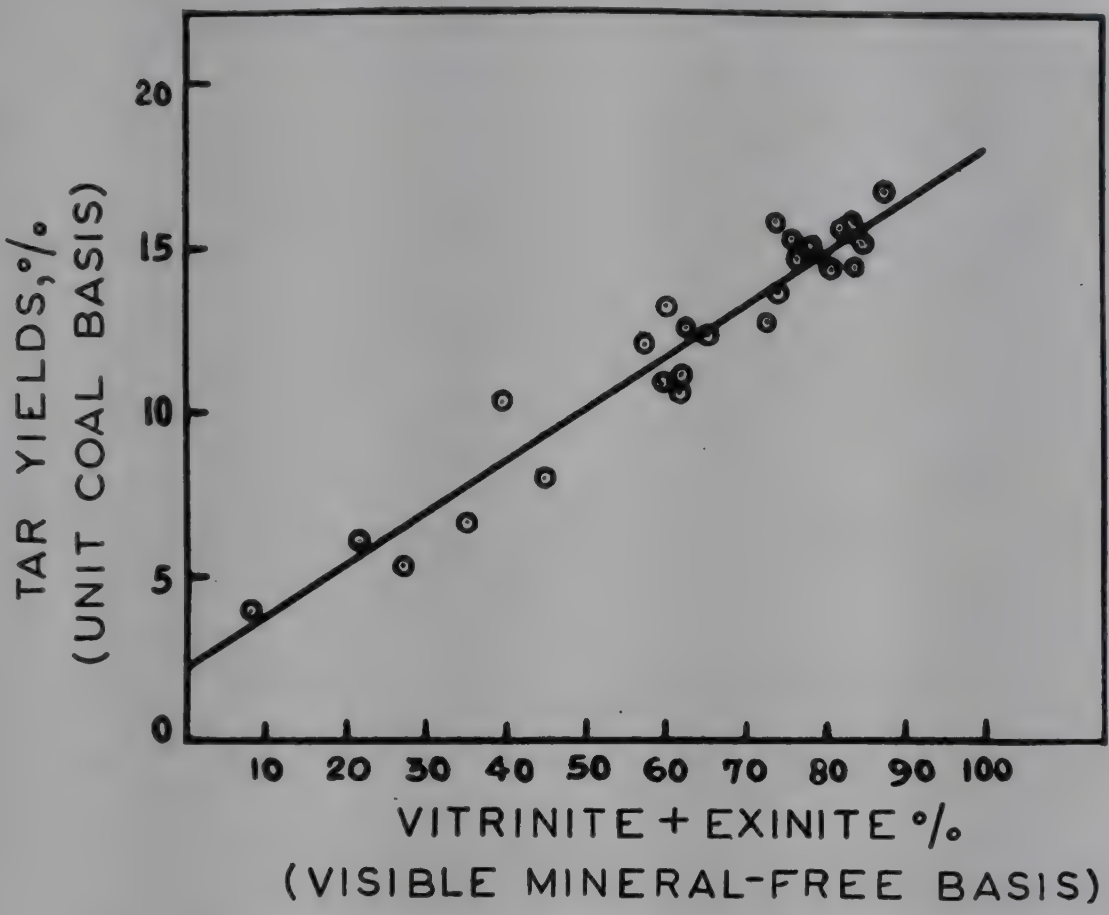

FIG. 1—RELATIONSHIP BETWEEN TAR YIELDS AND VITRINITE + EXINITE

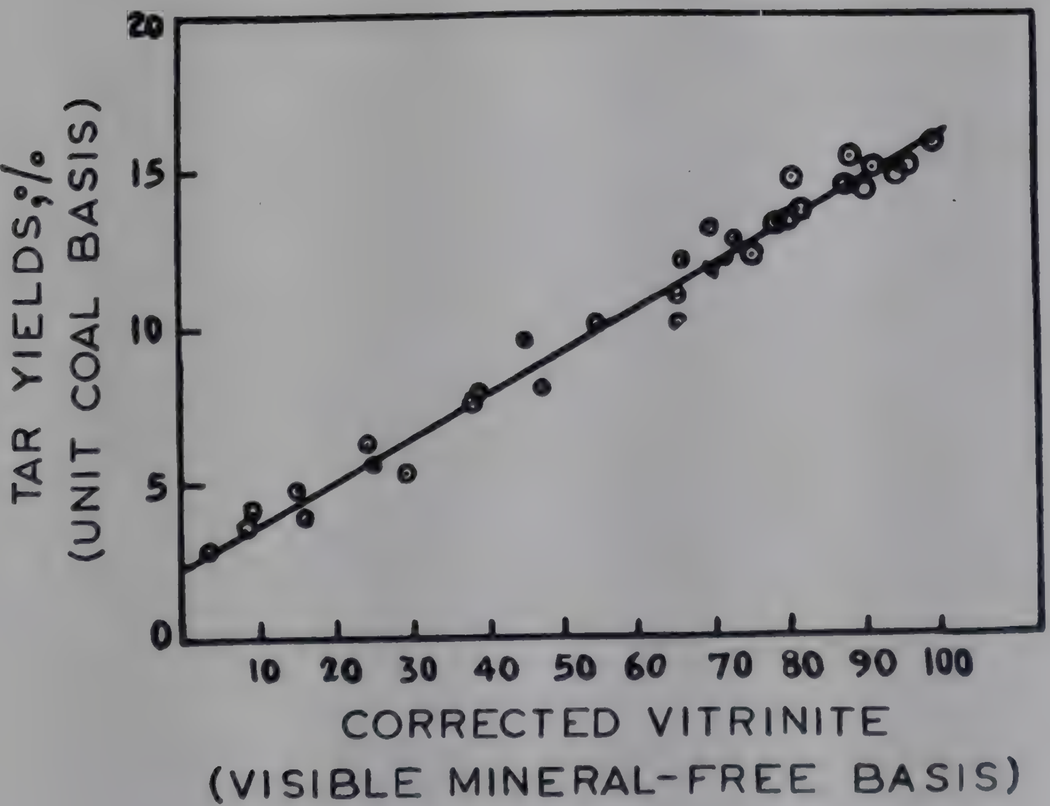

FIG. 2—RELATIONSHIP BETWEEN CORRECTED VITRINITE AND TAR YIELDS

From this relation, it should normally be possible to estimate tar yields, within 0·9 per cent of the experimental values.

In Fig. 1 a few points lie fairly off the line, thus statistically resulting in a broader linear relationship. This may be explained by the fact that a sharp increase or decrease in the exinite content is likely to shift such points beyond the tolerance range.

Further study on maceral concentrates by suitable gravity separation, centrifuging and deduction of chemical properties indicates that the tar yields of maceral exinites (spornites in particular) should be considered nearly twice that of vitrinite of the ranks examined. To accommodate this position and to bring out a closer linear relationship, it would be reasonable to convert the exinite to equivalent vitrinite to compensate for the presence of any high percentage of exinites over the normal.

Thus in Fig. 2 an improved linear relationship is shown by plotting the corrected vitrinite (total vitrinite obtained by conversion and correction, designated as corrected vitrinite) against tar yields from coals. The regression equation for such a plot works out to be:

$$Y = 2{\cdot}248 + 0{\cdot}14x_2 \tag{2}$$

where Y=Tar yields % (unit coal) from Gray-King l.t.c. assay, and

x_2=Corrected vitrinite.

The tar yields calculated from this relationship should normally give values closely comparable with the experimental figures, usually within 0·6 per cent; the mean arithmetical deviation for the predicted values is only 0·4 and lies almost within the range of experimental error. The correlation coefficient for this equation is 0·99. Although this relation should be considered to give values in close agreement with the determined ones, the relation from equation (1) and Fig. 1 has been observed to give reliable results in most of the cases except when the exinite contents are high.

From the foregoing observations it is fairly clear that the macerals, vitrinite and exinites are the main tar-yielding constituents of coals. Chemically, these are the same ingredients contributing mainly to the hydrogen content of a coal. The hydrogen content of exinite, however, is always higher than that of the associated vitrinites (being highest in resins and waxes), the latter may yield as high as 80 per cent or more of tar and oils. When resin contents in coal are too high, which is rare (except in some Assam coals), a further correction for the tar yield relationship will be required.

INERTINITE AND TAR YIELD

The macerals in the inertinite group being highly infusible constituents of coal behave more as inerts and hence contribute little towards the yield of tar and oil.

From the petrological nature and the chemical behaviour of these

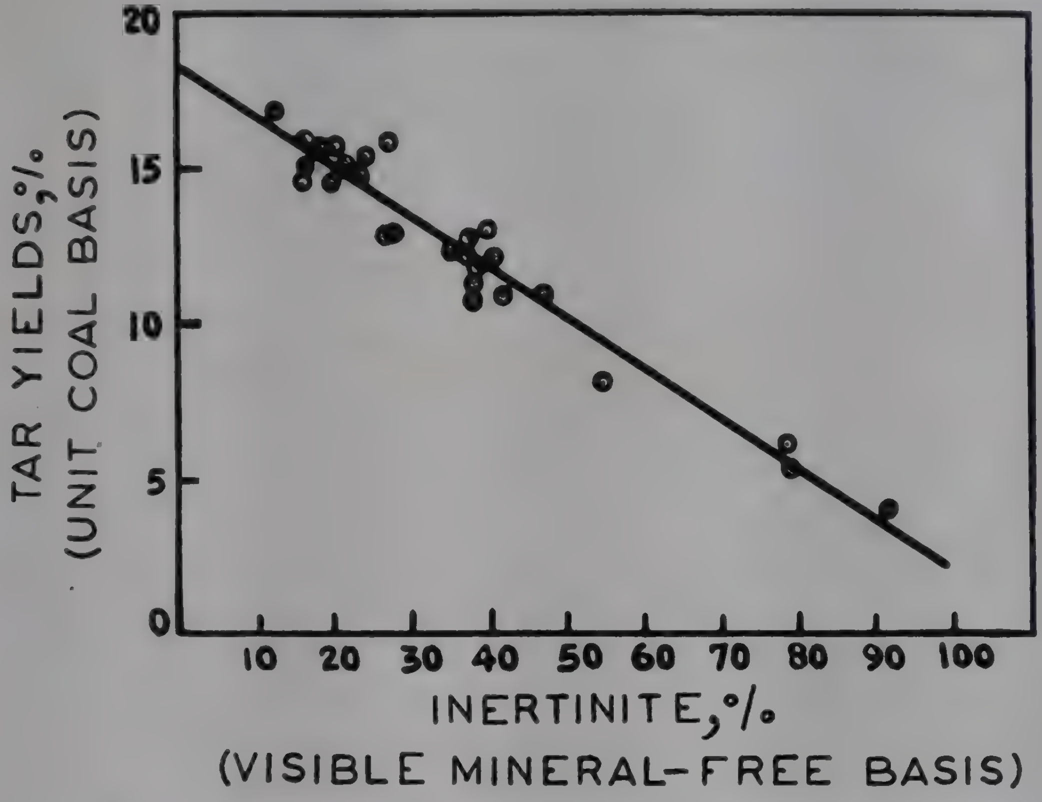

FIG. 3—RELATIONSHIP BETWEEN INERTINITE AND TAR YIELDS

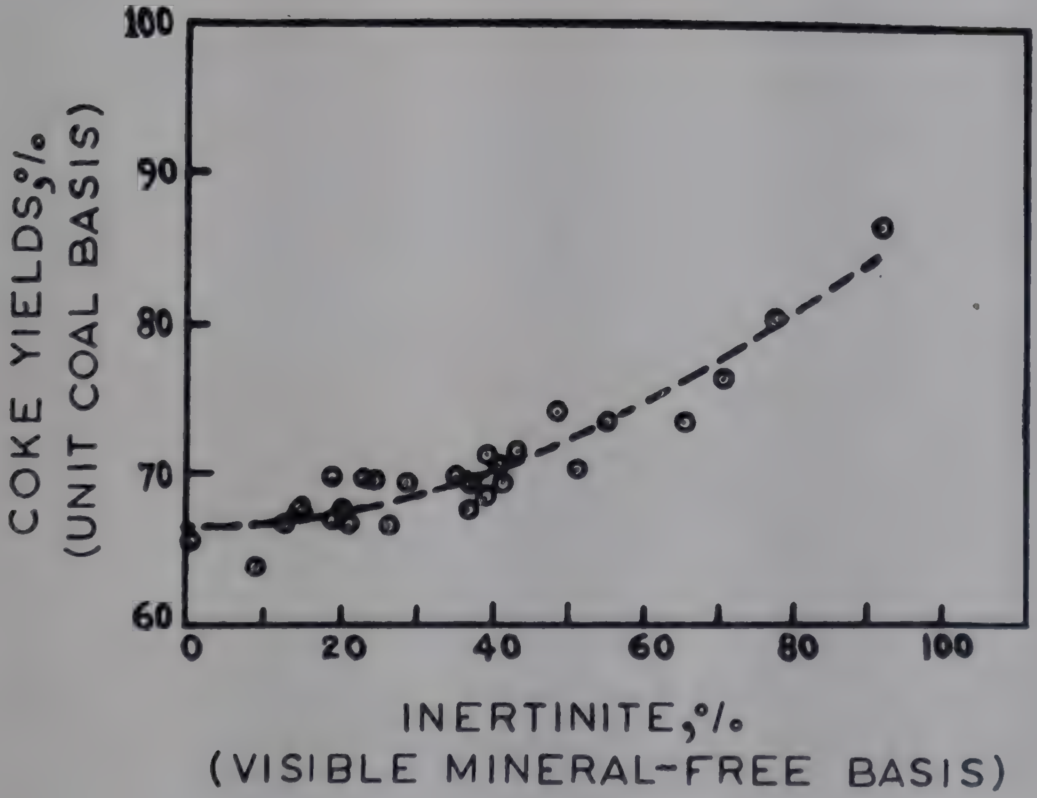

FIG. 4—RELATIONSHIP BETWEEN INERTINITE AND COKE YIELDS

TABLE 2—PETROGRAPHIC COMPOSITION* AND TAR YIELDS**
(low to medium rank coals)

Sl No.	Particulars	Vitrinite plus Exinite	Inertinite	Tar yield, %
1.	Hand picked fusain and purified by floating between sp. gr. 1·45 and 1·55, South Jhagrakhand Colliery, Sohagpur C.F.	8·2	91·8	4·0
2.	1·60-1·70 of float of coal crushed × 1/8″ of Upkanalla coal, Bisrampur C.F.	20·7	79·3	5·3
3.	Sink at 1·70 of coal crushed × 1/8″ Upkanalla coal, Bisrampur C.F.	21·5	78·5	6·1
4.	G-II Seam, Thin seam zone, Korba C.F.	22·9	77·1	5·2
5.	1·40-1·50 float of coal crushed × 1/8″ of Upkanalla coal, Bisrampur C.F.	35·0	65·0	6·7
6.	Upkanalla coal, Bisrampur C.F.	45·1	64·9	8·0
7.	Borehole core sample, Ghordewa Sector, Korba C.F.	27·2	72·8	7·5
8.	East Dongar Chickli coal, Pench Valley C.F.	57·3	42·7	12·1
9.	Borehole SJ-45, Bisrampur C.F.	58 6	41·4	11·7
10.	Ghorghella Nalla coal, Kurasia C.F.	59·8	40·2	10·9
11.	Burhar coal, Sohagpur C.F. (Exinite—18·5%)	59·8	40·2	13·3
12.	Ponri Hill coal, Kurasia C.F.	61·6	38·4	11·8
13.	Kurasia Bottom seam coal, Kurasia C.F.	61·7	38·3	11·2
14.	Ghordewa coal, Trial Incline, Korba C.F.	62·4	37·6	12·7
15.	Sink at 1·60 of coal crushed × 1/8″ Upper Kajora seam, Raniganj C.F.	62·8	37·2	12·2
16.	Nowrozabad coal, Johilla River C.F.	65·3	34·7	12·4
17.	Jamkunda coal, Pench Valley C.F.	70·6	29·4	12·4
18.	Gaimarah Bottom seam, Jhilimili C.F.	72·5	27·5	12·8
19.	Chanch Begunia seam, Raniganj C.F.	73·3	26·7	12·8
20.	Datla West coal, Pench Valley C.F. (Exinite —13·1%)	73·2	26·8	15·7
21.	1·40-1·50 sp. gr. float of coal crushed × 1/8″ Upper Kajora coal, Raniganj C.F.	74·0	26·0	13·7
22.	Ambara Adit Mines, Pench Valley C.F.	75·8	24·2	15·3
23.	Eklehra coal, Pench Valley C.F.	76·4	23·6	14·7

(Contd.)

TABLE 2—*Contd.*

SL No.	PARTICULARS	VITRINITE PLUS EXINITE	INERTINITE	TAR YIELD, %
24.	Jatraj coal, 4″–1″ size, cleans at 1·45 sp. gr. Korba C.F.	78·2	21·8	15·1
25.	Ramnagar coal, Kurasia C.F.	80·3	19·7	14·4
26.	Float at 1·30 of G-II Seam coal, Korba C.F.	80·5	19·5	15·0
27.	Jatraj seam coal, Korba C.F.	81·7	18·3	15·6
28.	Monoharbahal coal, Raniganj C.F.	83·2	16·8	15·4
29.	Burradhemo coal, Raniganj C.F.	83·4	16·6	15·5
30.	Upper Kajora coal, Raniganj C.F.	86·9	13·1	16·8
31.	1·30–1·40 sp. gr. float of coal crushed × 1/8″ of Upper Kajora coal, Raniganj C.F.	90·5	9·5	14·9
32.	Float at 1·30 of Kalichappar coal, Pench Valley C.F.	92·6	7·4	16·1
33.	Kurasia Top seam, Chirimiri C.F.	73·6	26·4	13·5
34.	1·50–1·60 sp. gr. float of coal crushed × 1/8″ Upper Kajora coal, Raniganj C.F.	60·2	39·8	13·0
35.	Middling at 1·45-1·70 sp. gr., 4″–1″ size, Jatraj coal, Korba C.F. (Exinite—35·2%)	59·8	40·2	15·0
36.	Picked fusain from Purewa seam, Singrauli C.F.	5·6	94·4	3·6
37.	Floats at 1·30 sp. gr. Bijuri coal, Sohagpur C.F.	96·2	3·8	15.8
38.	Floats at 1·30 sp. gr. Kurasia coal, Chirimiri C.F.	91·0	9·0	15·1

*On visible mineral-free basis.
**On unit coal basis.

inert macerals[6], and the characteristics of the macerals, vitrinite and exinite with respect to tar yields, it follows as a corollary that a kind of reverse relationship should exist between the tar yields and the macerals inertinites, the fusinites being the most inert of the group. This relationship is graphically represented in Fig. 3 and is expressed by:

$$Y = 18{\cdot}224 - 0{\cdot}161 x_3 \qquad (3)$$

where Y=Tar yields % (unit coal) from Gray-King l.t.c. assay, and

x_3=Inertinite % (visible mineral free).

A knowledge of inertinite content of coals should, therefore, indicate tar yields, normally within 0·9 per cent of the determined values.

INERTINITE AND COKE YIELD

It is well known that fusain (a common and predominant member of the inertinite group) is mostly composed of carbonized fragments and undergoes little fusion during carbonization. Other macerals of this group also behave largely as inerts and undergo little shrinkage during the process of carbonization[7]. Thus the inertinite group of macerals should largely be responsible for the yields of solid residues—char or coke. These also affect the type of coke produced.

A study of the petrographic composition of coals within the same rank (rank as indicated by the carbon content of vitrinites) in conjunction with l.t.c. data, indicates that increase in the coke yields is broadly proportional to the increase in the inertinite contents of such coals.

An attempt, therefore, to correlate such properties reveals the possibility of assessing the coke yields (within 1 per cent) from a knowledge of the inertinite contents of coals of low to medium rank. Such a relationship works out to be a curvilinear one as shown in Fig. 4 and may be represented by:

$$Z = 66{\cdot}258 + 0{\cdot}0114\, x_3 + 0{\cdot}00213\, x_3^2$$

where Z = Coke yield % (unit coal) from Gray-King l.t.c. assay,
and x_3 = Inertinite % (visible mineral free).

PETROGRAPHIC COMPOSITION AND GAS YIELDS

No attempt has been made to correlate gas yields with petrographic composition. A study of the segregated petrographic fractions by gravity separation of coals (crushed to $\frac{1}{8}$ in.) leads to certain general conclusions[6]. Petrographic components rich in vitrinites and including some exinites (about 90 per cent and 5 per cent respectively) yield the highest volume of gas, of the order of 13·5 l./g., whereas those comparatively rich in inert macerals (about 60 per cent) give a lower yield, about 10 l./g., the lowest being observed for fusinite (95 per cent inerts), 5·65 l./g. in the Gray-King assay. The gas is non-inflammable indicating that it contains a high percentage of carbon dioxide.

A knowledge of simple microscopic examination of coals could be used advantageously in understanding the physical constitution of coals and for the interpretation of certain chemical behaviour of coals on l.t.c.

However, it should be stated that these petrographic correlations hold good for the coals of low to medium rank levels with 84-85 per cent carbon, the rank being identified by carbon level of vitrinite and not on the overall coal. Carbon content of the overall coal has little relation with petrographic rank due mainly to the petrographic non-homogeneity that exists in coals, at least up to about 85 per cent carbon level (Table 3).

This is normally in keeping with the rank evolution of coals which is

TABLE 3—CORRECTED VITRINITE* AND TAR YIELDS**

(low to medium rank coal)

Sl No.	Particulars	Vitrinite	Exinite	Corrected vitrinite	Tar yield, %
1.	Hand picked fusain, South Jhagrakhand Colliery, Sohagpur C.F.	7·2	1·0	9·2	4·0
2.	Hand picked and centrifuged fusain, Hingir-Rampur C.F.	1·7	0·8	3·2	2·8
3.	Hand picked fusain, Singrauli C.F.	8·9	3·2	15·3	4·8
4.	Hand picked and centrifuged fusain, Orient Colliery, Hingir-Rampur C.F.	5·9	1·2	8·3	3·5
5.	Sectional sample, Borehole KJ-32, Kotma area, Sohagpur C.F.	14·9	4·8	24·5	6·2
6.	Sectional sample, Borehole G-207, Korba C.F.	12·7	6·1	24·9	5·4
7.	Sectional sample, Borehole G-156, Korba C.F.	16·4	10·8	38·0	7·5
8.	G-II Seam, Thin seam zone, Korba C.F.	16·2	6·7	29·6	5·2
9.	Middle section, North Chirimiri Colliery	21·8	8·3	38·4	7·8
10.	Rajnagar Colliery, Sohagpur C.F.	29·4	7·8	45·0	9·5
11.	Sectional sample, Borehole KJ-32, Kotma area, Sohagpur C.F.	46·3	9·5	65·3	10·9
12.	Sectional sample, Borehole KP-83, Kotma Block, Sohagpur C.F.	1·6	7·2	16·0	3·8
13.	Bottom section, North Chirimiri Colliery	49·4	8·1	65·6	10·0
14.	Sectional sample, Borehole KP-83, Sohagpur C.F.	34·1	10·1	54·3	10·1
15.	Upkanalla coal, Bisrampur C.F.	29·9	8·9	47·7	8·0
16.	Ponri Hill coal, Sohagpur C.F.	53·3	8·3	69·9	11·8
17.	East Dongarchickli coal, Pench Valley C.F.	48 6	8.7	66·0	12·1
18.	Burhar coal, Sohagpur C.F.	41·3	18·5	78·3	13·3
19.	Kurasia top seam coal	67·3	6·3	79·9	13·5
20.	Sp. gr. fraction, 1·30-1·40 Upper Kajora coal, Raniganj C.F.	86·0	4·5	95·0	14·9

(*Contd.*)

TABLE 3—*Contd.*

Sl No.	Particulars	Vitrinite	Exinite	Corrected vitrinite	Tar yield, %
21.	Sp. gr. fraction 1·40-1·50 Upper Kajora coal, Raniganj C.F.	66·2	7·8	81·8	13·7
22.	Sp. gr. fraction 1·50-1·60 Upper Kajora coal, Raniganj C.F.	50·8	9·4	69·6	13·0
23.	Sink at 1·60 sp. gr. Upper Kajora coal.	53·9	8·9	71·7	12·2
24.	Ghordewa coal, Trial Incline, Korba C.F.	51·6	10·8	73·2	12·7
25.	Nowrozabad coal	55·1	10·2	75·5	12·4
26.	Eklehra coal, Pench Valley C.F.	58·5	10·9	80·3	14·7
27.	Cleans at 1·45, Jatraj coal, Korba C.F.	65·5	12·7	90·9	15·1
28.	Floats at 1·30, G-II seam coal, Korba C.F.	73·3	7·2	87·7	14·4
29.	Middling at 1·45-1·70 sp. gr. 4″–1″ size, Jatraj coal, Korba C.F.	24·6	35·2	95·0	15·0
30.	Monoharbahal coal, Raniganj C.F.	78·4	4·8	88·0	15·4
31.	Floats at 1·30 sp. gr., Charcha coal, Sohagpur C.F.	84·8	7·1	99·0	15·8
32.	Ramnagar coal, Sohagpur C.F.	70·9	9·4	89·7	14·4
33.	Picked fusain from Purewa seam, Singrauli C.F.	5·2	0·4	6·0	3·6
34.	Floats at 1·30 sp. gr., Bijuri coal, Sohagpur C.F.	91·0	5·2	101·4	15·8
35.	Floats at 1·30 sp. gr., Kurasia coal, Chirimiri C.F.	86·9	4·1	95·1	15·1

*On visible mineral-free basis.
**On unit coal basis.

chiefly characterized by the gradual enrichment of carbon and is accompanied by other physico-chemical changes. The stage of geochemical transformation that manifests itself at about this rank, 85 per cent carbon level, causing significant changes in the entire character of coal, has been recognized from the physical nature and from the chemical constitution of coal[8]. As a result of completion of this stage of geochemical transformation the profound changes that take place in coal can generally be traced to a change in its technological behaviour, that is, by the incipient coking properties appearing for the first time at this carbon level.

TABLE 4—PETROGRAPHIC COMPOSITION* AND COKE YIELDS**

(low to medium rank coals)

SL No.	PARTICULARS	INERTINITE %	COKE YIELD, %
1.	Hand picked fusain and purified by floating between sp. gr. 1·45-1·55, South Jhagrakhand Colliery, Sohagpur C.F.	91·8	86·5
2.	G-II seam, Thin seam zone, Korba C.F.	77·1	80·5
3.	1·50-1·60 sp. gr. float of coal crushed × 1/8″ Upkanalla outcrop, Bisrampur C.F.	70·1	76·5
4.	1·40-1·50 sp. gr. float of coal crushed × 1/8″ Upkanalla outcrop, Bisrampur C.F.	65·0	73·5
5.	Upkanalla coal, Bisrampur C.F.	54·9	73·4
6.	Orient coal, Orissa	51·7	70·3
7.	Borehole SJ-69, Bisrampur C.F.	49·4	74·2
8.	East Dongar Chickli coal, Pench Valley C.F.	42·7	71·7
9.	Borehole SJ-45, Bisrampur C.F.	41·4	69·9
10.	Burhar coal, Sohagpur C.F.	40·2	70·4
11.	1·50-1·60 sp. gr. float of coal crushed × 1/8″ Upper Kajora seam, Raniganj C.F.	39·8	68·3
12.	1·30-1·40 sp. gr. float of coal crushed × 1/8″ Upkanalla outcrop, Bisrampur C.F.	39·5	71·3
13.	Sink at 1·60 sp. gr. of coal crushed × 1/8″ Upper Kajora seam, Raniganj C.F.	37·2	69·7
14.	Jatraj coal middlings at 1·45-1·70, 4″–1″ size, Korba C.F.	36·8	67·8
15.	Nowrozabad coal, Johilla River C.F.	34·7	69·9
16.	Jamkunda coal, Pench Valley C.F.	29·4	69·4
17.	1·40-1·50 sp. gr. float of coal crushed × 1/8″ Upper Kajora seam, Raniganj C.F.	26·0	66·8
18.	Ambara Adit Mines, Pench Valley C.F.	24·2	69·4
19.	Eklehra coal, Pench Valley C.F.	23·6	69·6
20.	Jatraj coal cleans at 1·45, 4″–1″ size, Korba C.F.	21·8	66·8
21.	Jatraj seam coal, Korba C.F.	20·4	67·6
22.	Ramnagar coal, Kurasia C.F.	19·7	69·8
23.	Float at 1·30 sp. gr. of coal crushed × 1/8″ G-III seam, Korba C.F.	19·5	66·8
24.	Float at 1·30 sp. gr. of coal crushed × 1/8″ Upkanalla outcrop, Bisrampur C.F.	15·1	67·9
25.	Upper Kajora coal, Raniganj C.F.	13·1	66·9
26.	1·30-1·40 sp. gr. float of coal crushed × 1/8″ Upper Kajora seam, Raniganj C.F.	9·5	63·9
27.	Float at 1·30 sp. gr. of coal crushed × 1/8″ Upper Kajora seam, Raniganj C.F.	1·7	65·4

*On visible mineral-free basis.
**On unit coal basis.

It is highly significant that this stage of change in the rank development as recognized chemically (by the carbon level) can also be identified under the microscope. The change that takes place in the character of vitrinite—changing abruptly its usual low to medium order of grey to a higher order of reflectance and refractive index[9,10]—is too evident to be overlooked. The petrographic relation explained, should, therefore, cease to function at this stage of metamorphic rank and calls for separate relations for the rank level up to 89/90 per cent carbon which again is marked by the completion of another stage of geochemical transformation[8].

The petrographic technique may also be usefully employed for the assessment of the l.t.c. potentialities of coals from a prospecting coalfield, where the only samples available are in the outcrops or from borehole cores. Chemical methods indicate erroneous results due to weathering of coal on storage.

Since most weathered coals still respond to the petrological examination by reflected light, quantitative determination of the petrographic composition can therefore be made and the primary products of l.t.c. may be assessed with reasonable accuracy using the formulae attempted.

The present investigation proves the development of a reliable quantitative petrographic technique which may profitably be employed in the elucidation of some problems pertaining to coal science. It is believed that with further refinement in the petrographic technique[11] a closer study of the chemical changes due to variations in petrography should be possible.

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DISCUSSION

Dr M. Vahrman: Apart from the use of petrology in the basic study of coal and in coal classification, and its main practical application in the selection and blending of coals in carbonization, it has been found useful in field surveys where it is required to assess the characteristics of the original coals from well-weathered samples.

For example, in work done on the evaluation of Queensland coals some twelve years ago it was possible to infer from the petrological characteristics of outcrop samples, so badly weathered as to have lost the characteristics of normal coals, that the material at depth was of the subhydrous, lignitous variety quite commonly found in Australia.

In evaluating the carbonization characteristics of coals and blends, petrology can act as a guide, but I do not think it can be regarded as a substitute for laboratory carbonization assays.

Low Temperature Carbonization Potentialities of Coals from the C. India and Orissa Coal fields

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Low temperature carbonization potentialities of coals from Central India and Orissa with special reference to their suitability for domestic coke manufacture are indicated. These data relate not only to the seams already being worked but also to the proved reserves in virgin areas. Certain correlations between tar yields and hydrogen content (both on unit coal basis) have been attempted, with a view to predict tar yields from ultimate analysis.

Though processing of coal for smokeless domestic fuel is a laudable objective, particularly in the context of the largely agrarian economy of India, its supply for large commercial plants presents some problems. The carbonization processes suitable for Indian conditions generally use coal of 3 to 1 in. size. This size constitutes only about 30 per cent if extracted by screening from the run-of-mine coal. It may be increased to about 50-55 per cent if run-of-mine coal is crushed and screened. Thus a commercial plant of, say, 1000 tons/day capacity will require 2000 tons of run-of-mine coal. Moreover, in this case the large sizes of coal will differ considerably in quality from the run-of-mine coal and, in particular, from the slack. Most of the mines in India are small and so it will be necessary to get the required supply from a number of sources, possibly even from different seams in a particular area for a central plant. Information on characteristics of coals of a region is therefore necessary for planning of any project.

Although coke is the major product in low temperature carbonization (l.t.c.), the economics of the industry depend entirely on byproduct yields, especially of the tar. An economic tar distillation unit should have a minimum capacity of 100 tons/day and hence emphasis in the selection of coal for l.t.c. must always be on the tar yields, provided the coke produced is strong enough for transport and suitable for combustion. Various attempts have therefore been made to predict tar yields from laboratory analyses and correlate the assay yields with some pilot plant and industrial plant yields. This information has been presented in another paper[1]. In view of the widely scattered occurrence of coal, it is necessary to classify coals according to their tar yields so that the coals of a particular area or seam could be considered for selection and interchange with those of other areas and seams. Considerable data have been collected in this regard by the Coal Survey Organization of the Central Fuel Research Institute, Jealgora. An earlier paper[2] gave a broad correlation of tar yields with hydrogen content of coal. This paper further classifies the coal into three groups, each having a linear relationship between hydrogen content and tar yield. From this the tar yields can be predicted within 1 per cent of the values obtained by Gray-King assay. Since Gray-King assay figures have been correlated with plant practice, the survey data can fairly accurately predict the tar yields in plants and may be used for preliminary selection of coal for tests.

COAL QUALITY

For sustaining commercial l.t.c. plants to supply domestic coke to the central, western, and, to an extent, north and north-western zones of India, coals from Central India and Orissa coalfields would form the source. These coalfields covering vast coal-bearing areas with large potential reserves of non-caking and weakly caking coals have so far remained practically unexploited and the coal output from them has been disproportionately small compared to Jharia and Raniganj coalfields. In view of the need to step up production and to conserve caking coals as also from the point of view of a balanced regional development and lessening strain on railway transport, a change in this position is fast taking place. A substantial increase in coal production from these areas is envisaged during successive Plan periods. It is considered opportune to present a generalized picture of the quality and potentialities of these coals to serve as a ready reference in the selection of coals for the l.t.c. projects. Tables 1 and 2 summarize the results on the quality and Gray-King low temperature assay of these coals.

CHOICE OF COAL

The coals suitable for l.t.c. processes can broadly be classified into two groups: (i) Weakly and semicaking coals including the slacks, and (ii) non-caking and feebly caking coals in lump sizes only (viz. 4 to 1 in. size). The coals should normally be of medium quality and, for economic considerations, those with higher yields of byproducts, specially tar and benzole, are preferable. It follows from Tables 1 and 2 that for coals in group (i),

TABLE 1—RANGES OF PROXIMATE ANALYSES
(on 60% R.H. at 40°C.)

COALFIELD	MOISTURE %	ASH %	VOLATILE MATTER %	FIXED CARBON %	REMARKS
1. Pench Valley Coalfield					
(*i*) No. 1 Seam	6-8·5	16-24	29-33	38-43	Moisture values in respect of coals from Datla West and Bhamori collieries lie between 2 and 4 per cent
(*ii*) No. 2 Seam	6·5-8·5	21-24	28-33	39-41	
(*iii*) Rawanwara collieries	7-9	13-17	31-34	46-50	
2. Kanhan Valley Coalfield					
(*i*) Working collieries	2-2·5	17-23	27-32	46-50	
3. Sohagpur Coalfield					
(*i*) Jhagrakhand group of collieries	5-7·5	11-19	26-30	47-52	
(*ii*) Other collieries	6-8	16-23	27-31	42-48	
(*iii*) Virgin coal bearing areas					
(*a*) Kotma Blocks IV & V					
Middle Seam	6-8·5	16-25	25-30	44-50	
Lower II Seam	8-9	13-18	25-29	48-54	
(*b*) Bijuri Block	4-6	12-21	28-31	45-51	
(*c*) Churcha Block	4-5	14-20	27-31	48-53	
(*d*) Sonhat Block A	2·5-4·5	28-34	27-30	37-42	
(*e*) Jhilimili area	3-4	14-18	28-32	49-53	
4. Chirimiri Coalfield					
(*i*) Working collieries	5-7	11-19	26-31	48-53	Moisture values in respect of Pure Chirimiri coals are of the order of 3%

(Contd.)

TABLE 1—*Contd.*

COALFIELD	MOISTURE %	ASH %	VOLATILE MATTER %	FIXED CARBON %	REMARKS
(*ii*) Virgin coal-bearing areas					
(*a*) TISCO Block I	5-6	14-17	28-32	49-54	
(*b*) TISCO Block II: Sonawani area :					
Southern side	5-6	19-24	27-30	43-47	
Eastern side	5-6	12-17	26-28	52-54	
Seams 'B' & 'C' of eastern area	7-8	13-20	28-32	47-52	
5. Bisrampur Coalfield					
(*i*) Virgin coal-bearing areas					
(*a*) Tata Blocks 'A', 'II' & 'C'	8·5-9·5	12-17	27-31	48-52	
(*b*) Tata Block I	3·5-5	11-18	28-31	50-56	
6. Singrauli Coalfield					
(*i*) Virgin coal-bearing areas					
(*a*) Moher Scrap Block					
Purewa Seam	7-9	21-25	31-35	35-41	
Turra Seam	7·5-9	15-19	29-31	44-46	
7. Korba Coalfield					
(*i*) Korba collieries	6-7	13-16	28-30	48-51	
(*ii*) Virgin coal-bearing areas					
(*a*) Ghordewa Seams (G-I & G-III) Blocks I & II	5-7	14-18	25-29	48-54	
(*b*) Thin Seam zone, Korba sector	6-7	12-14	27-32	49-54	
(*c*) *Jatraj Seam, Thick Seam zone	5-6	38-39	24-29	28-32	
8. Orissa Coalfield					
(*i*) Working collieries, Hingir-Rampur Coalfield	6-7·5	15-20	31-33	43-46	
(*ii*) Virgin coal-bearing areas, Talcher Coalfield					
(*a*) Blocks 'A', 'B' & 'C', Middle thick seam	6-7	28-31	28-32	33-37	
Bottom Seam (Quarriable zone)	8-9	15-19	30-32	42-45	

*Analysis on inclusion of bands.

the areas of interest are the western part of the Pench Valley coalfield, particularly the Datla West colliery area, the Kanhan valley coalfield with its northern and western extensions and the virgin areas of Bijuri, Churcha and Jhilimili in the Sohagpur coalfield. In the virgin Jhilimili area, substantial reserves of coals of the semicaking type are known to occur. These are yet to be proved by detailed prospecting. If confirmed, the Jhilimili coals would be eminently suited for l.t.c. These may also find an alternative use as blends in the manufacture of metallurgical coke. If the Kanhan valley coals are beneficiated for use in the manufacture of metallurgical coke, the middlings from the washery can be processed to produce soft coke.

For coals in group (ii) can be considered the Chirimiri and Jhagrakhand group of collieries, specially coals from the Chirimiri, New Chirimiri (Ponri Hill) and Rajnagar collieries, eastern and central parts of the Pench valley and the working collieries of the Hingir-Rampur coalfields. The large reserves of inferior coals from the thick Jatraj seam in the Korba coalfield also fall in this group. The l.t.c. assay results show that despite their high ash content the yields of tar from the coals of this seam are fairly good because of their high exinite content. However, in view of its inferior quality, utilization of this coal for the production of domestic coke is interlinked with an integrated scheme of beneficiation, carbonization and power generation. Such a scheme for maximum utilization of the huge coal reserves of the Jatraj seam has been earlier proposed by the authors[2].

In addition to the coals of groups (i) and (ii) mentioned above, large reserves of high-moisture, low-rank, non-caking coals have been recently proved in the virgin areas of the Bisrampur, Singrauli and Ghordewa seams of the Korba coalfields. Tar yields from these coals are rather low and the amount of fines in coke is likely to be high. Therefore, these coals in lump sizes should preferably be used in l.t.c. processes without byproduct recovery, obviously with somewhat reduced economic returns. Production of domestic coke would also provide an outlet for the disposal of middlings likely to be available from the proposed central washeries to be set up in the outlying coalfields.

The assessment presented above clearly shows that coals of the desired quality and quantity for different types of l.t.c. processes are available in the Central India and Orissa coalfields. Tar yields from many of these coals are fairly good and when processed yield about 55-66 per cent of total distillates containing on an average 13-18 per cent of tar acids. The tars thus form a suitable starting raw material for chemical industry.

HYDROGEN AND TAR YIELD

The exact nature of the known relationship between chemical composition of coal and its tar yield has to be worked out for different types of coal. Since coal is a heterogeneous material composed of varying proportions of petrological rock types like vitrain, durain, clarain and fusain, the relative proportions of these are likely to influence the coal properties as a whole. It is therefore necessary to know not only the percentage of hydrogen in a coal but also the distribution of the perhydrous and subhydrous ingredients in terms of different petrographic constituents in order to establish a relationship between tar yield and hydrogen content. Since facilities for petrographic analysis are not readily available, the relationships based on chemical composition of coal continue to be of practical value.

Evaluation of the above relationship for Indian coals[3] has shown that coals of the Central India and Orissa coalfields do not in general fit into this relationship, probably because of their petrographic peculiarities as compared to the more matured coals of the Jharia and Raniganj fields. Earlier, the authors putforth a separate relationship for these coalfields[2]. It was proposed that when sufficient data for these areas would become available the relationship should be re-examined and if necessary, modified for different areas.

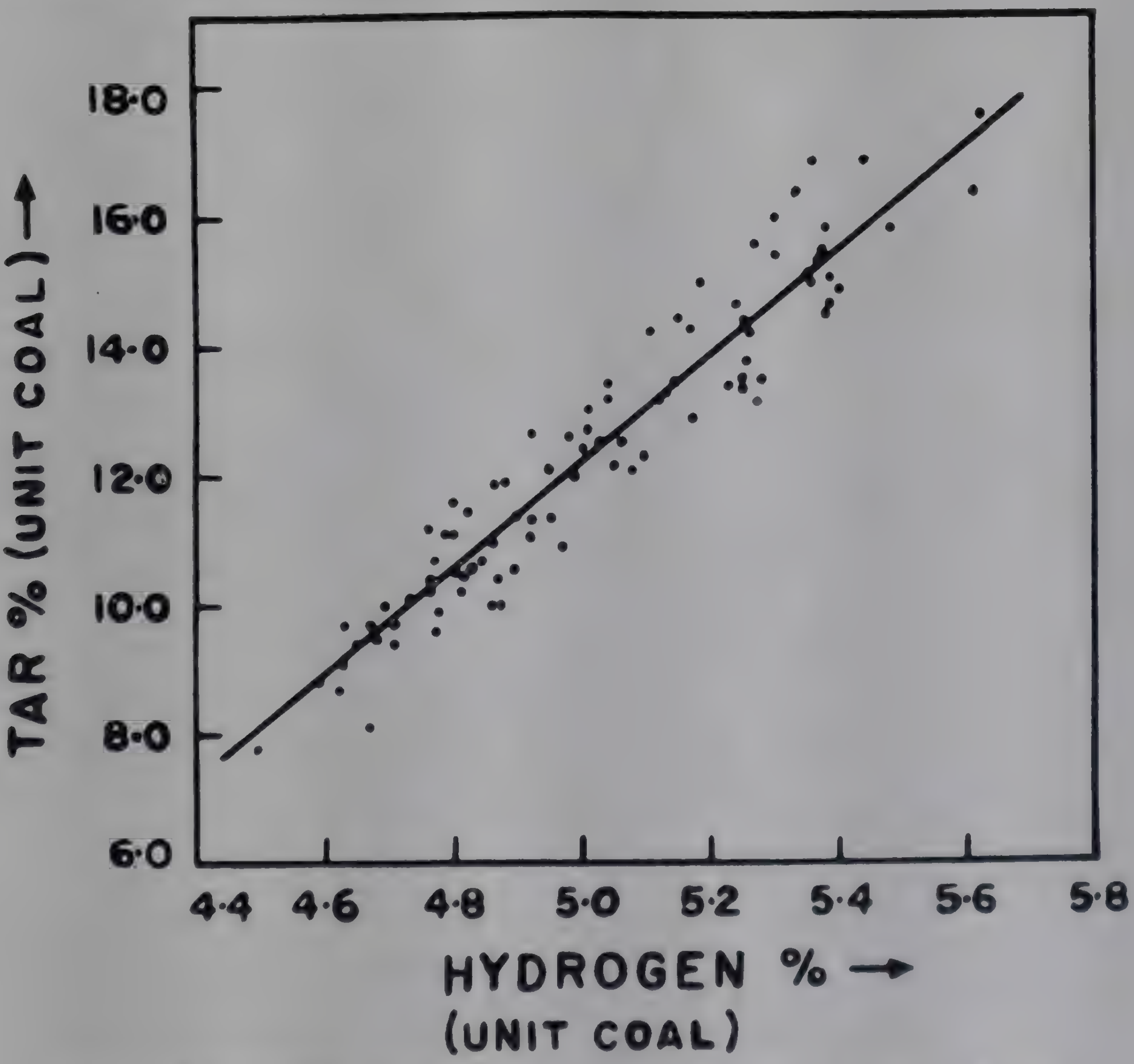

FIG. 1—RELATIONSHIP BETWEEN TAR YIELD AND HYDROGEN CONTENT—GROUP I

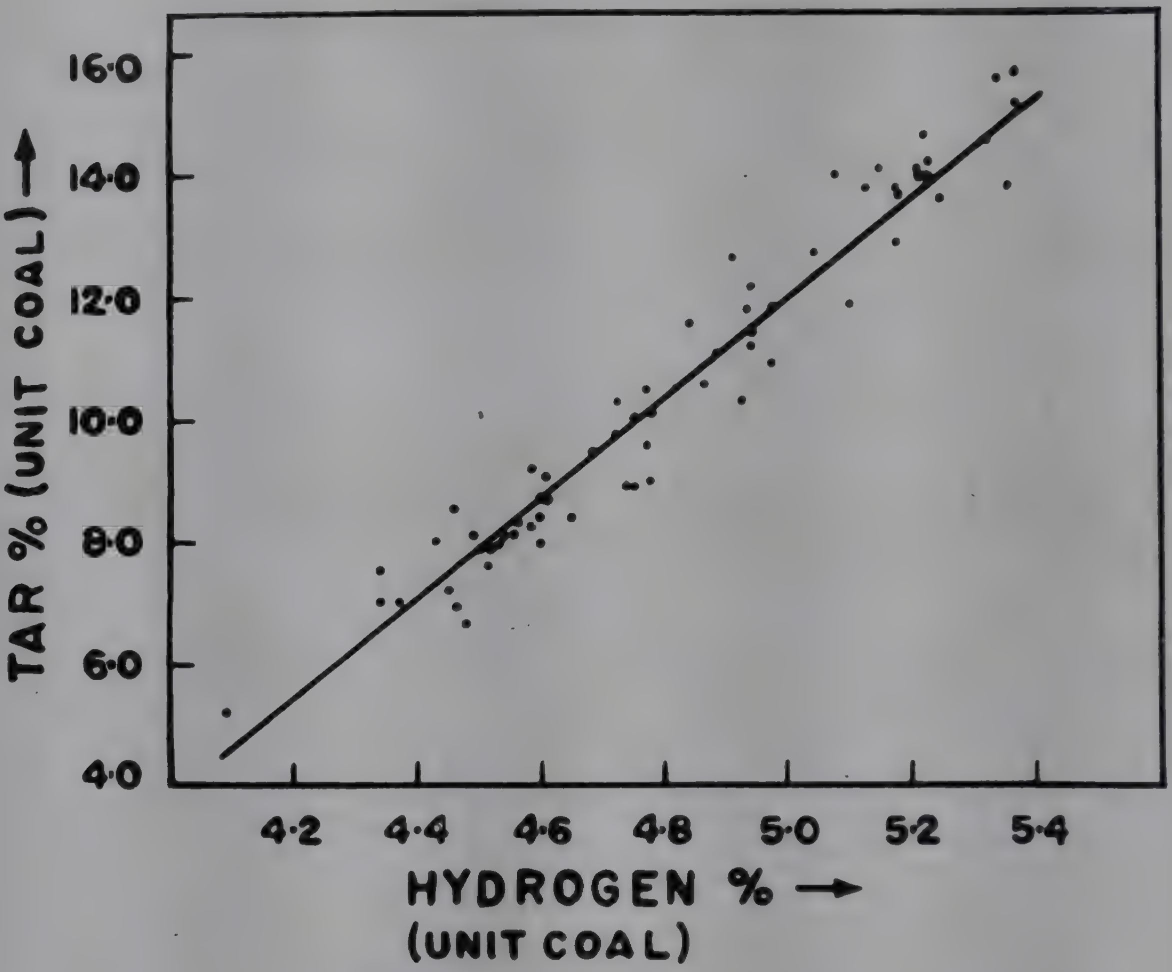

FIG. 2—RELATIONSHIP BETWEEN TAR YIELD AND HYDROGEN CONTENT—GROUP II

This has now been attempted in the light of analytical data of a large number of coal and core samples from the working and virgin areas. For the purpose of this relationship these coalfields can broadly be placed into three groups detailed below: Hydrogen per cent and tar yield here refer to unit coal basis.

Group I—Sohagpur, Chirimiri and Kanhan valley coalfields: Tar % = 8·37 × Hydrogen % − 29·61 (i).

Group II—Bisrampur, Singrauli and Korba coalfields: Tar % = 8·26 × Hydrogen % − 29·28 (ii).

Group III—Pench valley and Orissa coalfields: Tar % = 7·86 × Hydrogen % − 25·62 (iii).

For the above relationships the statistical analyses reveal high values of correlation coefficient the values being 0·95, 0·97 and 0·91 for (i), (ii) and (iii) respectively.

Association of different areas in the same group is suggestive of the coals being either of similar petrographic composition or of having a set of different petrographic combinations giving the same overall effect for the hydrogen and tar yields. Grouping together of the Bisrampur, Singrauli and Korba coalfields and that of the Sohagpur and Chirimiri coalfields

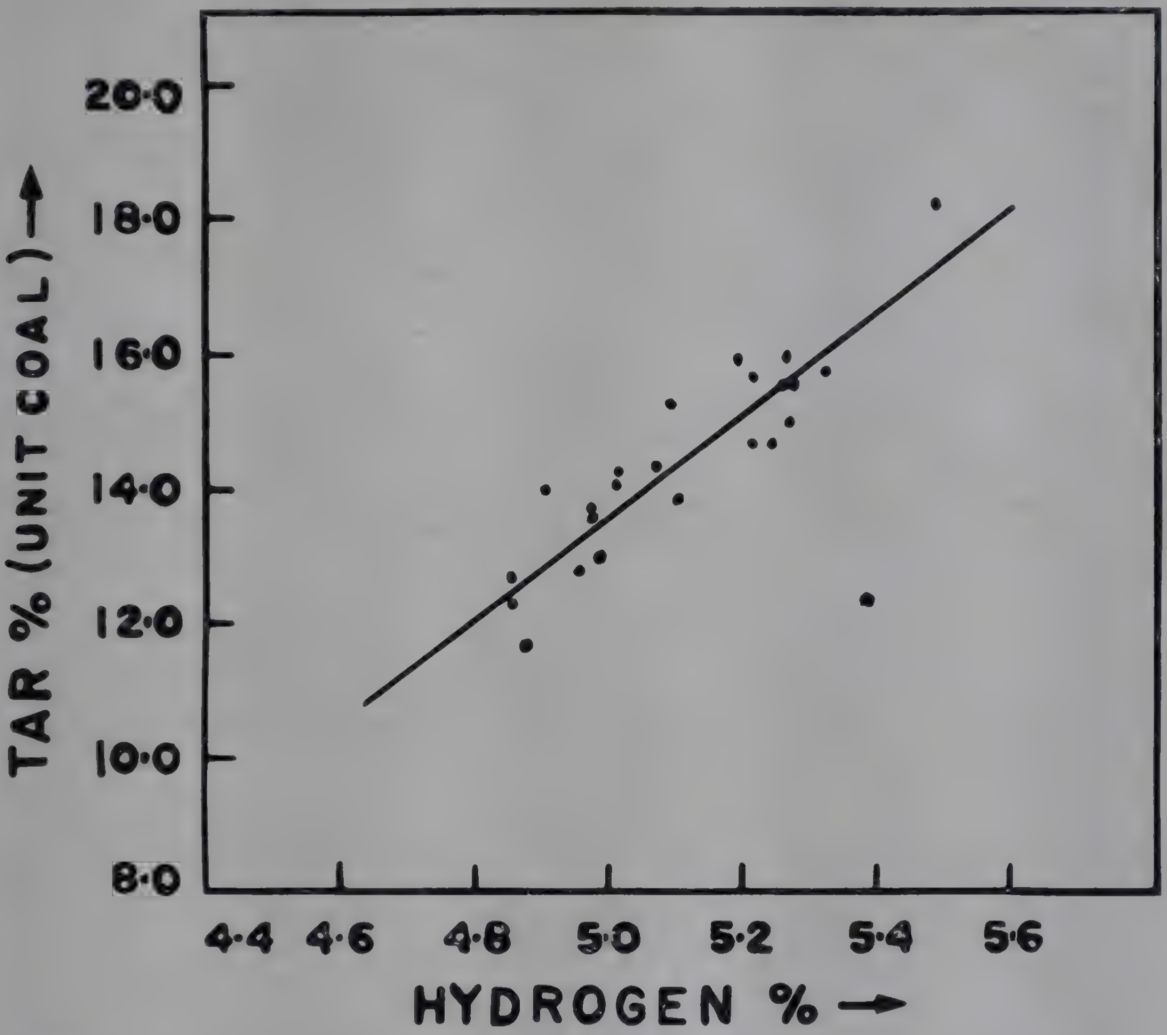

FIG. 3—RELATIONSHIP BETWEEN TAR YIELD AND HYDROGEN CONTENT—GROUP III

is possibly an instance of the former type, whereas grouping of the Pench valley and Orissa coalfields an instance of the latter type. The position of Kanhan valley coals is a little different, and is possibly influenced by its higher rank than other coals in the region. Coals from the Pure Chirimiri (Chirimiri coalfield) and Rawanwara (Pench valley coalfield) collieries are an exception to this broad grouping as they, instead of fitting in the group of their respective fields, have to be placed elsewhere, i.e. Pure Chirimiri in Group III and Rawanwara in Group I. Examination of this aspect shows that the properties of the Pure-Chirimiri coal are clearly distinct from those of other coals in the Chirimiri coalfield and, therefore, its migration to other group is to an extent explicable. However, the position of Rawanwara coals needs further examination.

For each of the Groups I, II, and III, the relationship between the hydrogen content and tar yield (both expressed on unit coal basis) from Gray-King assay at 600°C. is graphically shown in Figs. 1, 2 and 3 respectively. As shown in Tables 3, 4 and 5 the experimental and the calculated tar yields compare fairly well, agreeing within ±1 per cent with a few exceptions.

TABLE 2—RANGES OF YIELDS OF PRODUCTS FROM GRAY-KING ASSAY AT 600°C.
(per ton of dry coal)

Coalfield	Coke (cwt)	Tar (gal.)	Liquor (gal.)	Gas cu. ft at 60° F. & 30 in. (sat.)	Coke type	Remarks
1. Pench Valley Coalfield Working collieries	14·5-15·8	20-28	11-15	2700-3650	•Generally 'B'	'C' type coke for coals from Datla West colliery
2. Kanhan Valley Coalfield Working collieries	15-16	24-28	6-10	3000-3700	D-G	
3. Sohagpur Coalfield						
(*a*) Working collieries	15-16	18-25	10-15	2700-3500	A-B	'C' type coke for coals from Rungta colliery
(*b*) Virgin coal-bearing areas						
(*i*) Kotma Blocks IV & V	15-16	17-24	12-15	2800-3500	A-B	
(*ii*) Bijuri Block	15-15·5	23-27	8-12	2900-3300	B-C	
(*iii*) Churcha Block	15-16	20-25	10-13	2750-3400	B-C	
(*iv*) Sonhat Block A	15·5-16	22-28	9-13	2600-3000	B-D	
(*c*) Jhilimili area	15·3-15·8	23-26	9-11	3000-3400	C	
4. Chirimiri Coalfield						
(*a*) Working collieries	14·5-16	18-24	9-13	2800-3600	A-B	Coals from the Pure Chirimiri Colliery yield C to E type coke and the tar yield from a 5-ft coal seam is about 34 gals/ton
(*b*) Virgin coal-bearing areas						
(*i*) Tisco Block I	15-15·5	19-20	12-13	2900-3500	Inf. A-B	
(*ii*) Tisco Block II	15-16	17-20	12-14	3200-3600	A-B	

(Contd.)

TABLE 2—*Contd.*

COALFIELD	COKE (cwt)	TAR (gal.)	LIQUOR (gal.)	GAS cu. ft at 60° F. & 30 in. (sat.)	COKE TYPE	REMARKS
5. Bisrampur Coalfield						
Virgin coal-bearing areas						
(*i*) Tata Blocks ‘A’, ‘II’ & ‘C’	14·5-16·0	13-17	14-16	3200-3900	A-Inf. B	
(*ii*) Tata Block I	15·5-16·0	20-22	10-11	2800-3500	B	
6. Singrauli Coalfield						
Virgin coal-bearing area						
(*i*) Moher Scarp Block	14·5-15	15-20	14-17	3400-3700	A-Inf. B	
7. Korba Coalfield						
Virgin coal-bearing areas						
(*i*) Jatraj seam, thick seam zone	15-16	18-20	14-16	2600-3000	A	
(*ii*) Ghordewa seams, Blocks I & II	15-16	13-19	11-15	2800-3500	A-Inf. B	
8. Orissa Coalfield						
(*i*) Working collieries, ‘Hingir-Rampur Coalfields’	15-15·7	20-25	13-14	2450-3350	B	
Virgin coal-bearing area, Talcher Coalfield						
(*ii*) Blocks ‘A’, ‘B’ & ‘C’	14·5-15	20-26	13-17	2600-3300	A-B	

Note: Data for virgin areas are based on investigations on borehole coal cores or exploratory samples.

TABLE 3—EXPERIMENTAL AND CALCULATED YIELDS OF TAR (on unit coal basis) FROM GROUP I COALS OF THE SOHAGPUR, CHIRIMIRI AND KANHAN VALLEY COALFIELDS

(Using the Formula, T=8·37H—29·61)

Sl No.	Colliery or Area, etc.	Hydrogen (unit coal basis) %	Tar yield (unit coal basis) Gray-King assay at 600°C. %	Tar yield (unit coal basis) (calculated) %	Difference (calculated-experimental)
	(*a*) Sohagpur Coalfield				
1.	South Jhagrakhand	4·89	10·54	11·32	0·78
2.	North Jhagrakhand	5·10	12·29	13·08	0·79
3.	West Jhagrakhand	4·92	11·26	11·57	0·31
4.	,,	4·92	11·06	11·57	0·51
5.	Rajnagar	4·64	9·45	9·23	—0·22
6.	Ramnagar	5·25	14·39	14·33	—0·06
7.	Kotma	4·59	8·82	8·81	—0·01
8.	Bhadra	4·87	11·92	11·15	—0·77
9.	Burhar	5·13	13·26	13·33	0·07
10.	,,	5·13	13·32	13·33	0·01
11.	,,	5·25	13·25	14·33	1·08
12.	West Burhar	5·27	15·57	14·50	—1·07
13.	Rungta	5·39	14·69	15·50	0·81
14.	Kotma Block IV	5·17	13·03	13·66	0·63
15.	,,	4·83	10·46	10·82	0·36
16.	,,	4·71	9·40	9·82	0·42
17.	,,	5·04	13·19	12·57	—0·62
18.	Kotma Block V	5.03	12·53	12·49	—0·04
19.	,,	5·04	13·53	12·57	—0·96
20.	,,	4·81	10·24	10·65	0·41
21.	,,	4·63	9·09	9·14	0·05
22.	,,	4·76	10·41	10·23	—0·18
23.	,,	4·95	11·04	11·82	0·78
24.	,,	4·63	9·74	9·14	—0·60

(Contd.)

TABLE 3—*Contd.*

Sl No.	Colliery or Area, etc.	Hydrogen (unit coal basis) %	Tar yield (unit coal basis) Gray-King assay at 600°C. %	Tar yield (unit coal basis) (calculated) %	Difference (calculated-experimental)
25.	Kotma Block V	4·67	8·04	9.48	1·44
26.	„	4·62	8·70	9·06	0·36
27.	„	5·08	12·10	12·91	0·81
28.	„	4·71	9·68	9·81	0·13
29.	Bijuri Block	5·24	14·72	14·25	—0·47
30.	„	4·99	12·01	12·16	0·15
31.	„	5·36	15·04	15·25	0·21
32.	„	5·39	15·12	14·50	0·38
33.	„	5·14	13·51	13·41	—0·10
34.	„	5·38	15·91	15·42	—0·49
35.	„	5·15	14·45	13·50	—0·95
36.	„	5·11	14·25	13·16	—1·09
37.	„	5·01	12·70	12·32	—0·38
38.	Churcha Block	5·26	14·17	14·42	0·25
39.	„	4·92	11·27	11·57	0·30
40.	„	4·82	11·48	10·73	—0·75
41.	„	4·95	12·13	11·82	—0·31
42.	„	4·77	10·72	10·31	—0·41
43.	„	4·92	12·65	11·57	—1·08
44.	„	4·98	12·56	12·07	—0·49
45	„	4·80	11·12	10·57	—0·55
46.	„	5·19	15·01	13·88	—1·18
47.	„	5·25	13·54	14·33	0·79
48.	„	4·88	11·92	11·24	—0·68
49.	„	5·06	12·52	12·74	0·22
50.	Sonhat Block 'A'	5·44	16·90	15·92	—0·98

(*Contd.*)

TABLE 3—*Contd.*

SL No.	COLLIERY OR AREA, ETC.	HYDROGEN (unit coal basis) %	TAR YIELD (unit coal basis) Gray-King assay at 600°C. %	TAR YIELD (unit coal basis) (calculated) %	DIFFERENCE (calculated-experimental)
51.	Sonhat Block 'A'	5·37	15·49	15·34	—0·15
52.	,,	5·61	16·36	17·358	0·99
53.	,,	5·30	15·37	14·75	—0·62
54.	,,	5·33	16·44	15·00	—1·44
55.	,,	5·62	17·58	17·43	—0·15
56.	,,	5·36	16·90	15·25	—1·65
57.	Gaimarh seam at Sardih	5·12	13·15	13·24	0·09
58.	Sardih area	5·01	13·04	12·32	—0·72
59.	Katkona area	5·00	12·41	12·24	—0·17
60.	Bandakhoh area	5·17	14·31	13·66	—0·65
	(*b*) Chirimiri Coalfield				
61.	Kurasia	5·28	13·50	14·58	1·08
62.	,,	5·23	13·41	14·17	0·76
63.	,,	4·69	10·02	9·65	—0·37
64.	,,	4·78	9·91	10·40	0·49
65.	,,	4·76	11·20	10·23	—0·97
66.	,,	4·79	11·08	10·48	—0·60
67.	Chirimiri	4·85	11·33	10·98	—0·35
68.	New Chirimiri	4·80	11·61	10·57	—1·04
69.	,,	4·87	10·40	11·15	0·75
70.	North Chirimiri	4·86	9·96	11·07	1·11
71.	West Chirimiri	4·77	9·64	10·31	0·67
72.	Ghorghela Nala area	4·97	10·90	11·99	1·09
73.	TISCO Block I	4·84	10·73	10·90	0·17
74	,,	4·86	10·90	11·07	0·17

(*Contd.*)

TABLE 3—*Contd.*

Sl No.	Colliery or Area, etc.	Hydrogen (unit coal basis) %	Tar yield (unit coal basis) Gray-King assay at 600°C. %	Tar yield (unit coal basis) (calculated) %	Difference (calculated-experimental)
75.	TISCO Block	4·80	10·48	10·57	0·09
76.	TISCO Block II	4·49	7·76	7·97	0·21
77.	,,	4·65	9·37	9·31	—0·06
78.	,,	4·73	10·11	9·98	—0·13
79.	,,	4·87	10·00	11·15	1·15
80.	,,	4·76	10·34	10·23	—0·11
	(*c*) Kanhan Valley Coalfield				
81.	Damua	5 40	14·89	15·59	0.70
82.	Kalichhapar	5·35	15·11	15·17	0·06
83.	,,	5·37	15·40	15·34	—0·06
84.	Rakhikole	5·38	14·52	15·42	0·90
85.	,,	5·48	15·85	16·26	0·41
86.	Ghorwani Kalan	5·30	15·95	14·75	—1·20
	(*d*) Others				
87.	Rawanwara Colliery Pench Valley Coalfield	5·26	13·77	14·42	0·65
88.	,,	5·05	12·23	12·66	0·43
89.	,,	5·17	12·90	13·66	0·76
90.	,,	4·90	11·41	11·40	—0·01
91.	Birsingpur Colliery Johilla Coalfield	4·81	10·50	10·65	0·15

TABLE 4—EXPERIMENTAL AND CALCULATED YIELDS OF TAR (on unit coal basis) FROM GROUP II COALS OF THE BISRAMPUR, SINGRAULI AND KORBA COALFIELDS

(Using the formula $T=8{\cdot}26H-29{\cdot}28$)

SL No.	COLLIERY OR AREA	HYDROGEN (unit coal basis) %	TAR YIELD (unit coal basis) Gray-King assay at 600°C. %	TAR YIELD (unit coal basis) (calculated) %	DIFFERENCE (calculated-experimental)
	(*a*) Bisrampur Coalfield				
1.	Upkanala area	4·60	7·98	8·72	0·74
2.	Tata Block A & II	4·50	7·94	7·89	—0·05
3.	,,	4·65	8·41	9·13	0·72
4.	,,	4·51	7·56	7·97	0·41
5.	,,	4·75	8·86	9·96	1·10
6.	,,	4·49	8·13	7·81	—0·32
7.	,,	4·72	9·81	9·71	—0·10
8.	,,	4·34	6·96	6·57	—0·39
9.	,,	4·74	8·89	9·87	0·98
10.	,,	4·45	7·21	7·48	0·27
11.	Tata Block I	4·88	11·11	11·03	—0·08
12.	,,	4·94	11·38	11·52	0·14
13.	,,	4·97	11·88	11·77	—0·11
	(*b*) Singrauli Coalfield				
14.	Moher Scrap Block	4·72	10·26	9·71	—0·55
15.	,,	4·43	7·98	7·31	—0·67
16.	,,	4·56	8·28	8·39	0·11
17.	,,	4·75	10·02	9·96	—0·06
18.	,,	5·17	12·85	13·42	0·57
19.	,,	4·97	10·94	11·77	0·83
20.	,,	5·17	13·67	13·42	—0·25
	(*c*) Korba Coalfield				
21.	Ghordewa Trial Incline	5·04	12·72	12·35	—0·37
22.	Ghordewa Blocks I and II	4·59	9·16	8·63	—0·53

(Contd.)

TABLE 4—*Contd.*

SL No.	COLLIERY OR AREA	HYDROGEN (unit coal basis) %	TAR YIELD (unit coal basis) Gray-King assay at 600°C. %	TAR YIELD (unit coal basis) (calculated) %	DIFFERENCE (calculated-experimental)
23.	Ghordewa Blocks I and II	4·59	8·21	8·63	0·42
24.	,,	4·91	12·68	11·28	—1·40
25.	,,	4·46	8·53	7·56	—0·97
26.	,,	4·78	10·05	10·20	0·15
27.	,,	4·92	10·25	11·36	1·11
28.	,,	4·93	11·80	11·44	—0·36
29.	,,	4·78	9·00	10·20	1·20
30.	,,	4·94	11·21	11·52	0·31
31.	,,	4·61	9·06	8·80	—0·26
32.	,,	4·84	11·55	10·70	—0·85
33.	,,	4·48	6·63	7·72	1·09
34.	,,	4·54	8·06	8·22	0·16
35.	,,	4·09	5·21	4·50	—0·71
36.	,,	4·30	7·48	6·24	—1·24
37.	,,	4·77	9·57	10·12	0·55
38.	,,	4·60	8·69	8·72	0·03
39.	,,	4·77	10·48	10·12	—0·36
40.	,,	4·37	6·95	6·82	0·13
41.	,,	4·47	6·92	7·64	0·72
42.	,,	4·53	7·98	8·14	0·16
43.	,,	4·60	8·36	8·72	0·36
44.	Ramsagar inclines, Korba Colliery	4·52	7·88	8·06	0·18
45.	Thin Seam Zone, Korba Sector	4·68	9·52	9·38	—0·14
46.	,,	4·61	8·65	8·80	0·15
47.	,,	4·55	8·14	8·30	0·16
48.	Thin Seam Zone, Rajgamar Sector	5·10	11·92	12·85	0·93

(Contd.)

TABLE 4—*Contd.*

Sl No.	Colliery or Area	Hydrogen (unit coal basis) %	Tar yield (unit coal basis) Gray-King assay at 600°C. %	Tar yield (unit coal basis) (calculated) %	Difference (calculated-experimental)
49.	Thin Seam Zone, Rajgamar Sector	5·35	13·76	14·91	1·15
50.	,,	5·17	13·72	13·42	—0·30
51.	Pilot Quarry, Jatraj Seam	5·33	15·57	14·75	—0·82
52.	Thick Seam Zone, Korba	5·22	14·16	13·84	—0·32
53.	,,	5·14	14·13	13·18	0·95
54.	,,	5·07	13·99	12·61	—1·38
55.	Thick Seam Zone, Korba	5·20	14·05	13·67	—0·38
56.	,,	5·36	15·20	14·99	—0·21
57.	,,	5·20	14·02	13·67	—0·35

TABLE 5—EXPERIMENTAL AND CALCULATED YIELDS OF TAR (on unit coal basis) FROM GROUP III COALS OF THE PENCH VALLEY AND ORISSA COALFIELDS

(Using the formula, $T=7{\cdot}86H-25{\cdot}62$)

Sl No.	Colliery or Area	Hydrogen (unit coal basis) %	Tar yield (unit coal basis) Gray-King assay at 600°C. %	Tar yield (unit coal basis) (calculated) %	Difference (calculated-experimental)
	(*a*) Pench Valley Coalfield				
1.	Datla West	5·27	15·64	15·80	0·16
2.	,,	5·26	15·97	15·72	—0·25
3.	,,	5·21	15·66	15·33	—0·33
4.	,,	5·19	15·96	15·17	—0·79
5.	Eklehra	5·26	15·56	15·72	0·16
6.	,,	5·24	14·72	15·57	0·85
7.	,,	5·32	15·82	16·20	0·38
8.	Jatachhapa	4·90	14·01	12·89	—1·12
9.	Ambara 4 and 5 Adit	5·09	15·31	14·39	—0·92

(Contd.)

TABLE 5—*Contd.*

Sl. No.	Colliery or Area	Hydrogen (unit coal basis) %	Tar yield (unit coal basis) Gray-King Assay at 600°C. %	Tar yield (unit coal basis) (calculated) %	Difference (calculated-experimental)
10.	East Dongar Chickli	4·97	13·66	13·44	—0·22
	(*b*) Orissa Coalfield				
11.	Orient	5·01	14·32	13·76	—0·56
12.	,,	4·97	13·55	13·44	—0·11
13.	Hingir-Rampur	5·01	14·07	13·76	—0·31
14.	,,	4·98	13·02	13·52	0·50
15.	Blocks A, B & C	5·21	14·69	15·33	0·64
16.	,,	4·87	11·69	12·66	0·97
17.	,,	4·95	12·77	13·29	0·52
18.	,,	5·27	14·96	15·80	0·84
19.	,,	5·10	13·88	14·47	0·59
20.	,,	4·85	12·25	12·50	0·25
	(*c*) Others				
21.	Pure Chirimiri Colliery, Chirimiri Coalfield	4·85	12·77	12·50	—0·27
22.	,,	5·07	14·37	14·23	—0·14
23.	,,	5·48	18·29	17·45	—0·84

Note: The L.T.C. data of the samples collected from the Pench Valley Coalfield during survey in 1957 has not been considered in this study.

It has been shown[3] that the ratio of tar yield on carbonization in the Narrow Brick Retort at 650°C. to that in Gray-King assay at 600°C. is about 0·66. Using this ratio the likely yields of tar in actual plant practice can be assessed from the Gray-King assay data. For areas where Gray-King assay data are not available, the tar yields can be reasonably predicted from the hydrogen content of the coals.

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DISCUSSION

Dr M. Vahrman: The amount of hydrogen in a present-day coal will depend on the proportions of its ancestral plant components, which varied considerably in hydrogen content, and the extent and type of coalification that these have undergone. Thus, the correlations between tar yield and percentage of hydrogen are valid for groups of coals of similar parentage and coalification history. But, as in the case of petrological examinations, they cannot substitute for the carbonization tests themselves.

Shri B. S. Deshmukh: The correlation between hydrogen and tar yield was not meant to replace actual carbonization tests. There should be some quick methods to study carbonization properties of different coals before proceeding to actual carbonization tests. The correlation is useful for preliminary assessment of tar yields. The limitations of this method have also been brought out in our paper.

Studies on Low Temperature Carbonization of Some Indian Coals

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Low temperature carbonization studies on low rank, high moisture, high volatile, non-caking to strongly caking coals from Assam, Bengal, Bihar, Madhya Pradesh and Maharashtra are presented. The detailed analyses given of coke, tar, liquor and gas from Fischer and Gray-King assays and from semi-pilot oven tests presented are useful in evaluating the low temperature carbonization potentialities of various coals.

States like Assam, Bengal, Bihar, Maharashtra and Madhya Pradesh propose to instal low temperature carbonization (l.t.c.) plants of large capacities in the Third Five Year Plan period. To obtain the necessary technical data required for the preparation of project reports for installation of such plants, the Central Fuel Research Institute undertook detailed investigations on the l.t.c. of suitable coals from these regions. The selection of coals is based upon their physical and chemical properties and l.t.c. characteristics (yields of products expected and their quality). The latter were determined in laboratory, bench and semi-pilot scale units. The coals tested belong mostly to the lower rank, high moisture, high volatile, completely non-caking to strongly caking types.

COALS TESTED

About two dozen coals from the Raniganj coalfield in West Bengal, the B. R. K. coalfield in Bihar and various fields in Assam, Maharashtra and M. P. were selected for testing, largely because they were abundantly available. Apart from their availability, they had other characteristics such as high volatile matter content and low ash content thus giving higher yields of tar and gas and optimum yields of coke, liquor and gas spirits.

Tests were carried out generally on the 1-3 in. size fraction (excepting for Gray-King assays), as this would be the most suitable size for carbonization in large-scale plants. In the case of Assam coals the test charge consisted of the 0·5-3 in. fraction as the amount of the 1 in. fraction was too small. Assam coals being highly caking in nature, even the 0·5 in. size could easily be charged in full-scale retorts. Thus owing to the size restriction only 65-85 per cent of R.O.M. coals could be utilized in the carbonization tests.

The coals tested were subjected to the usual sampling procedure and screen, petrographic, proximate and ultimate analyses. Determinations of bulk density of the test charges as well as the caking index and calorific values of samples were also made. Some samples were subjected to the usual physical tests and Hardgrove grindability test to assess their strength and grindability properties. Table 1 summarizes the properties of the coals.

TESTING EQUIPMENT AND PROCEDURE

Laboratory Tests. For the Gray-King and Fischer assays the respective standard apparatus and methods were used[1,2,3].

Semi-pilot Scale Carbonization Tests in an Electrically Heated Oven (Fig. 1). About 230 to 250 lb. of 1-3 in. sized coal charge is filled in a rectangular mild steel retort of 44 in. height, 27 in. major axis and 10 in. width. It is then sealed by welding, providing a 2 in. gas outlet and a 0·5 in. sheath for a thermocouple for measuring temperature at the centre of the charge. The retort is heated along its major axis on both sides. While the rear and side walls of the oven are fixed, the front wall is movable. The electrical heating elements are embedded in the front and rear walls. When walls attain a temperature, about 100°C., lower than the chosen wall temperature, retorts are generally introduced into the oven from the top. Carbonization is carried out under conditions of controlled heating and when carbonization temperature as measured at the centre of coke mass is finally reached, the test charge is then maintained steady at that temperature for some time. Only when gas evolution from the retort tapers off, it is taken out from the oven and cooled in air with its gas outlet closed. The retort is then cut open to discharge the coke for laboratory analysis and physical testing.

The carbonization gases pass through a byproduct train consisting of tube and shell type coolers for condensation of heavier and lighter tar fractions, an electrostatic precipitator for removal of tar mist, a sodium-bicarbonate scrubber for hydrogen sulphide removal, and scrubbers for absorption of light spirit fractions from gas. Finally the gas is metered before storage in a gas holder.

TABLE 1—PROPERTIES OF SOME COALS FROM VARIOUS FIELDS

SOURCE OF COAL	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M.P. AND MAHARASHTRA	ASSAM
Number of coals tested	Three	Two	Six	Two	Three	Three	Three
Names of seams and collieries (the latter in brackets)	Jambad-Bowlah (Sankerpore), Jambad-Bowlah (Jaipuria-Kajora) and Upper Kajora (Moira)	Taltore (Ikrahnandi) and Ghusick (Damra)	Koithee (Jamuria A+B), Salanpur 'A' (Bonjemahari), Burradhemo (Nag's Ramji-Wanpur), Bharatchalk (Chinakuri), Satgram (New Satgram), Bogra (New Satgram)	Raghunathbati (Dhamomain) and Hatnal (Seetalpur)	Argada (Bhurkunda), Sirka (Bhurkunda) and Kuju top (Kugu)	No. 3 (Rawanwara), Majri (Majri) and Top and Bottom mixed (Ballanpur)	Top and Bottom seams (Tipong), 20′ seam (Namdung) and Top and Bottom Sec. (Baragolai)
Proximate analysis, air-dried basis, %							
Moisture	5.3 - 6·3	6·0 - 6·2	1·6 - 6·9	2·4 - 2·7	3·5 - 5·2	4·8 - 6·4	1·3 - 1·8
Ash	14·1 -18·5	17·2 -21·9	14·8 - 26·0	15·9 - 22·6	20·7 - 27·1	15·1 - 20·8	2·5 - 5·3
Volatile matter	34·8 -36·1	31·2 -32·0	23·1 - 36·0	33·0 - 34·2	27·4 - 31·9	30·3 - 32·5	43·4 - 44·2
Fixed carbon	41·4 -43·5	40·7 -44·8	40·7 - 49·3	41·7 - 47·5	41·0 - 42·9	42·6 - 47·6	49·7 - 50·5
Ultimate analysis, d.m.m.f. basis, %							
Carbon	80·4-81·6	82·00-82·70	82·20-89·50	83·80-84·70	82·21-85·09	80·39-83·34	79·42-82·12
Hydrogen	5·2- 5·4	5·32- 5·35	4·39 - 5·68	5·73 - 5·75	5·15 - 5·70	4·80 - 4·97	5·42 - 6·05
Sulphur	0·4- 0·4	0·50- 0·64	0·44 - 0·60	0·52 - 0·62	0·66 - 1·07	0·83 - 1·39	2·24 - 6·47
Nitrogen	1·8- 1·9	1·81- 2·45	1·70 - 2·48	2·44 - 2·82	1·61 - 2·16	1·78 - 1·95	1·00 - 1·37
Oxygen	10·9-11·9	8·89- 9·86	3·94 - 9·51	6·49 - 7·13	6·83 - 9·70	9·13- 11·77	7·29 - 9·73

(Contd.)

TABLE 1—*Contd.*

SOURCE OF COALS	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M.P. AND MAHARASHTRA	ASSAM
Number of coals tested	Three	Two	Six	Two	Three	Three	Three
Calorific value, air dried basis, Btu/lb.	10,590-11,015	10,170-10,730	10,250-11,590	10,950-12,040	9,690-10,300	9,910-11,320	13,450-14,220
Caking Index (B.S.)	less than 3	2-3	5-10	15	3-5	less than 3	20-21
Petrographic analysis (% wt)							
Vitrinite	74·0-82·0	73·9 - 79·8	47·2 - 80·9	68·4 - 72·2	47·5 - 58·4	47·2 - 80·5	61·0 - 88·3
Exinite	2·5- 7·1	4·3- 6·8	4·5 - 14·8	8·7 - 10·5	4·2 - 5·8	3·5 - 5·1	3·3 - 4·3
Inertinite	14·0-18·9	15·9 -19·3	14·5 - 38·0	17·2 - 22·9	37·4 - 46·7	16·0 - 47·7	7·4 - 35·3
Bulk density of the 1-3 in. coal charge, used for SPO and Fischer-tests, lb./cu.ft	..	46·6 -50·6	46·0 - 51·5	45·0 - 47·0	44·8 - 50·0	41·6 - 43·1	45·0 - 47·8
Screen analysis of the 1-3 in. coal charge used for SPO and Fischer tests (% cumulative)							
+ 2 in.	43·8-56·2	41·3 -69·0	34·5 - 74·4	47·3 - 76·5	40·0 - 56·8	51·9 - 59·2	24·8 - 60·5
+ 1 in.	92·6-94·4	93·1 -98·5	88·5 - 99·5	87·8 - 99·5	93·4 -99·0	92·2 - 99·6	63·2 -100·0
+0·5 in.	95·9-98·9	95·6 -99·5	97·5 -100·0	93·2 -100·0	97·9 -100·0	96·5 -100·0	86·8 -100·0
—0·5 in.	1·1- 2·0	0·5 - 4·4	0·0 - 2·5	0·0 - 6·8	0·0 - 2·1	0·0 - 3·5	0·0 - 13·2

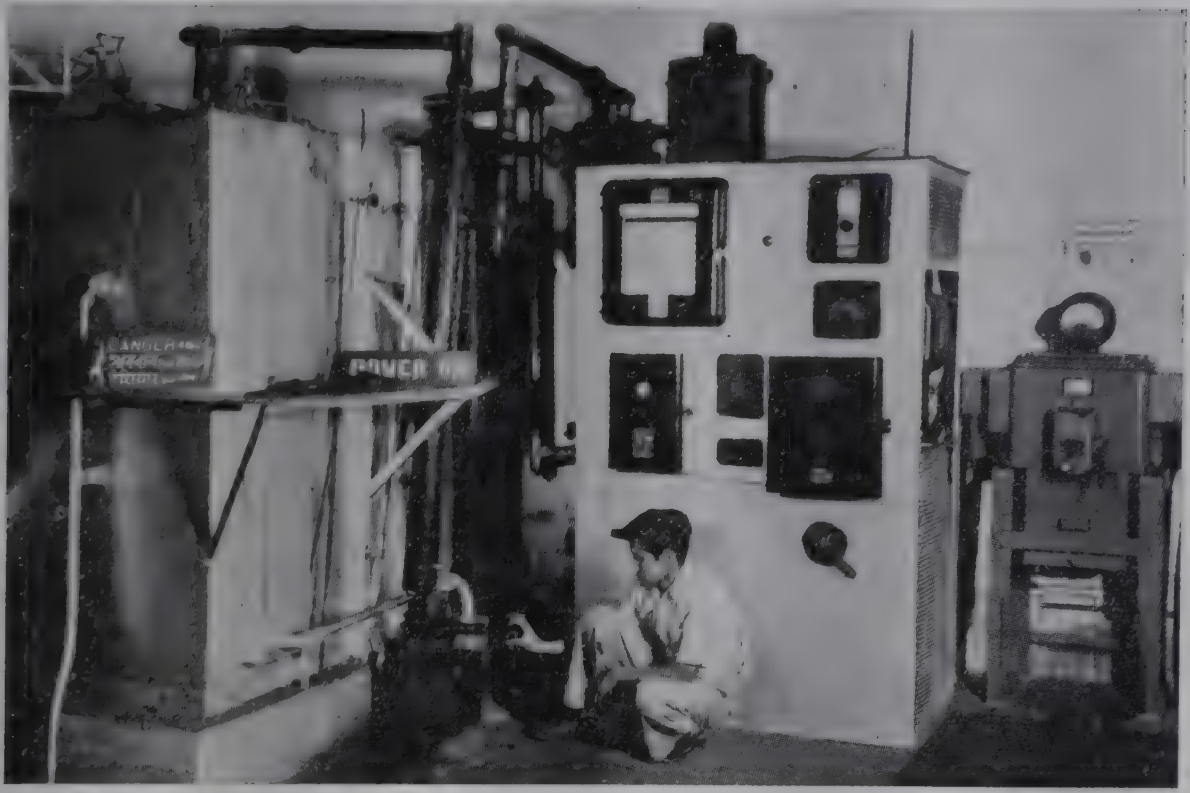

FIG. 1—ELECTRICALLY HEATED OVEN FOR SPO TESTS

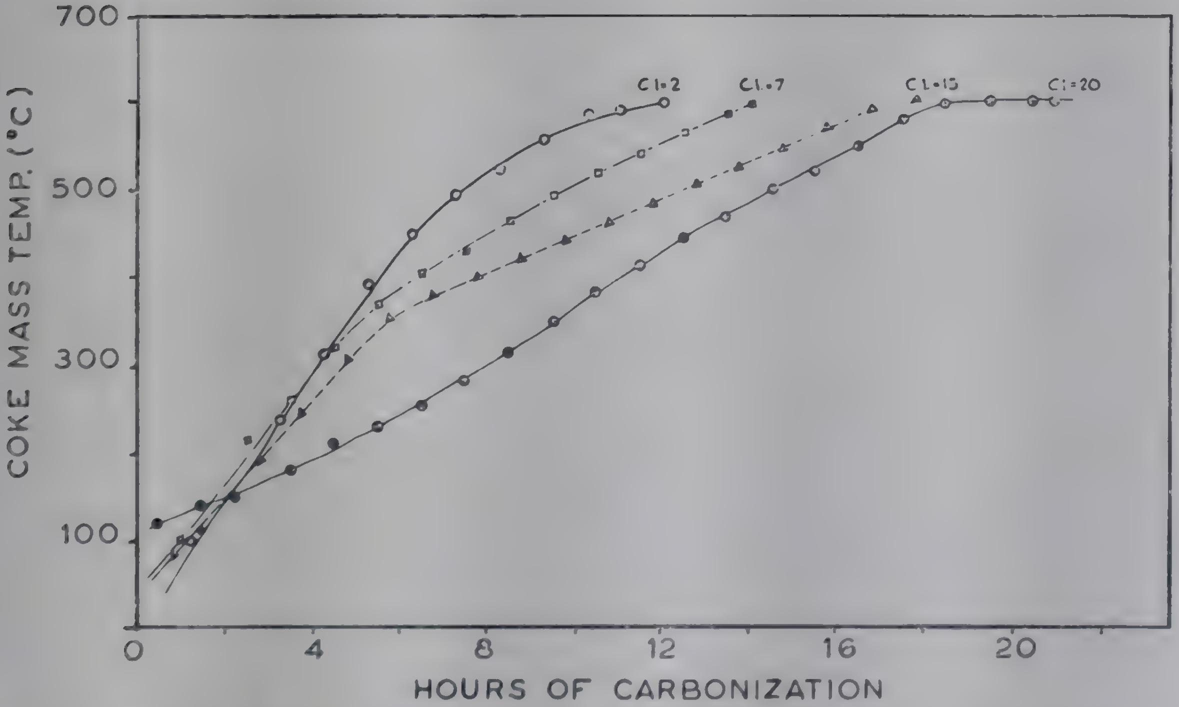

FIG. 2—COKE MASS TEMPERATURE VS HR OF CARBONIZATION (Electric oven – 300 lb.): Tipong Colliery 1-3″ Assam Caking Index 20 Dhemomain Colliery 1-3″ Raghunathbati seam 1-3″ Caking Index 15 Chinakuri Colliery Bharat Chalk seam 1-3″ Caking Index 7 Damra Colliery Ghusiek seam 1-3″ Caking Index 2

The carbonization tests in semi-pilot oven (hereafter called SPO) were generally carried out up to a final coke mass temperature of 600°C. except in a few cases, when the temperature of coke mass was raised to 650°C. to produce cokes with comparatively low volatile matter contents, for use in low shaft furnace as fuel and for production of ferro-manganese. The period of carbonization varied from 10-20 hr, depending mainly on the caking index of the coals, and to some extent on the quantity of the test charge and the temperature of carbonization.

The rise in carbonization temperature was kept as smooth as possible in all the experiments. Fig. 2 shows the dependence of the period of carbonization on the caking index of coal. Fig. 3 shows the hourly rate of gas evolution for the duration of carbonization tests in SPO for the same four coals. The curves are significant in that coals with lower caking index show a steep initial rise in the gas evolution rate. The gas evolution rate was constant for 2, 8 and 7 hr for coals with caking indices of 7, 15 and 20 respectively. The coal with caking index of 2 did not show constant gas evolution rate period and the fall in gas rate was very rapid during the later half of the carbonization period for this coal unlike the other coals with higher caking indices. The constant gas evolution rate was higher for Assam coal due to its higher volatile matter content.

YIELDS OF CARBONIZATION PRODUCTS

The results obtained have been summarized in Table 2. The Gray-King assay generally gave lower coke yields of coke and higher yields of tar and gas than the Fischer assay, while no particular trend was noticeable for liquor yields; this may be explained by the slightly higher temperature adopted for the Gray-King assay and the difference in the method of carbonization. The SPO tests generally gave lower yields of tar and higher yields of liquor and gas than both Gray-King and Fischer assays, no particular trend being noticeable for coke yields. The tar fumes suffer considerable cracking during their upward passage to the gas outlet in the SPO, due to the higher wall temperatures maintained, causing a decrease in the yield of tar and increase in the yield of gas. The caking properties of the charge determine the extent to which the tar fumes are likely to be subjected to cracking. In the case of highly caking coals, the tar fumes meet with greater resistance in their passage upward, as a result of which cracking takes place to a greater extent, increasing the deposition of carbon residue on coke pieces. The latter causes increase in the coke yields, which thus depends upon not only upon temperature and mode of carbonization but also upon the carbonizing properties of coals. In the Fischer and Gray-King assays tar vapours are not cracked to the same extent as they are in SPO.

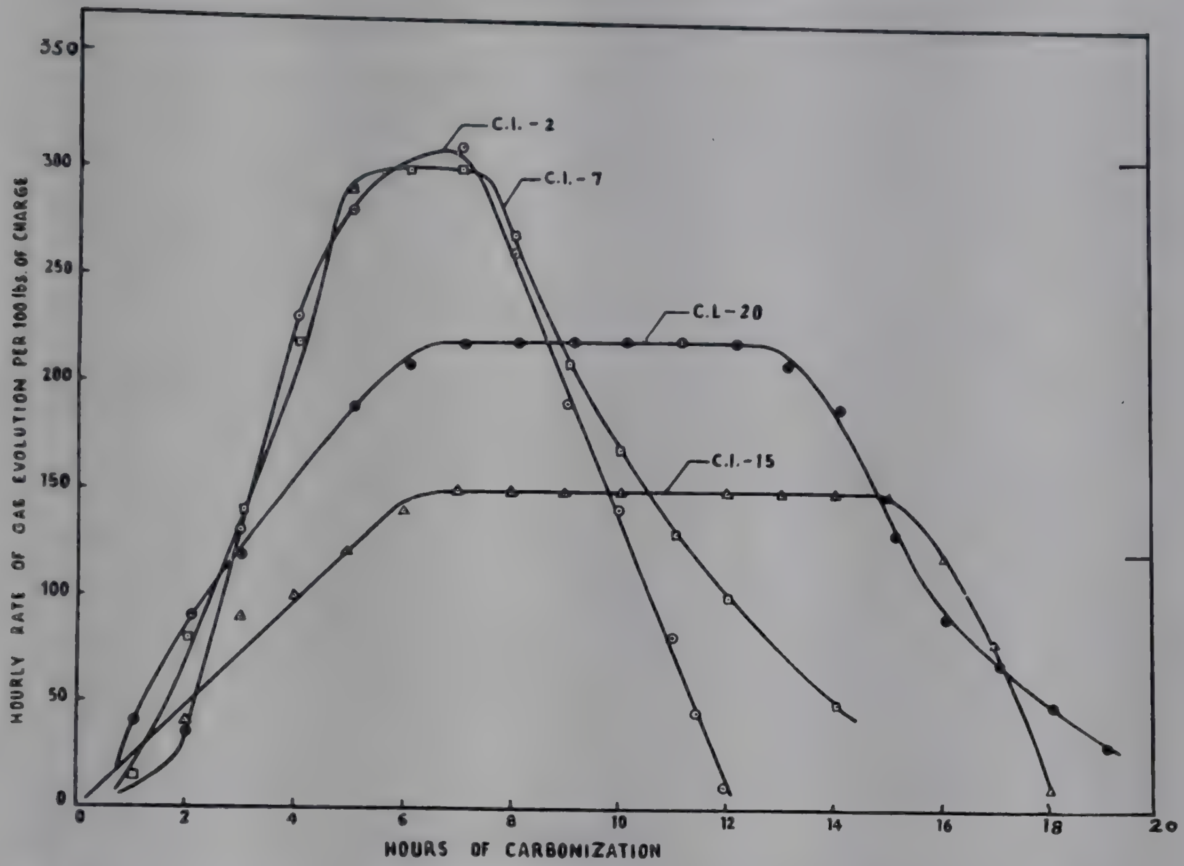

FIG. 3—HOURLY RATE OF GAS EVOLUTION VS HR OF CARBONIZATION (Electric oven—300 lb.): Tipong Colliery 1-3″ Assam Caking Index 20 Dhemo main Colliery 1-3″ Raghunathbati seam Caking Index 15 Chinakuri Colliery 1-3″ Bharat Chalk seam Caking Index 7 Damra Colliery 1-3″ Ghusiek seam Caking Index 2

In the SPO, the yields of products per ton of coal carbonized ranged as below:

Coke, cwt	13·5—16·6
Tar, gal.	8·1—19·5
Liquor, gal.	11·0—23·5
Gas, cu. ft	3620—6350

The yields of gas spirits in both SPO and Fischer tests varied approximately between 1 to 2 gal. per ton of coal carbonized. The Assam coals gave the lowest yield of coke and the highest yields of tar and gas. Higher yields of coke and lower yields of gas were obtained for high ash, comparatively low volatile and slightly higher rank coals from Raniganj and B. R. K. fields. In the Raniganj group, while the Bharatchalk seam coal gave the lowest yield of coke and highest yields of tar and gas, the Salanpur seam coal gave the highest yield of coke and the lowest yields of tar and gas. The yields and properties of different carbonization products from Maharashtra and M. P. coals showed that these samples had suffered considerable weathering prior to their testing.

Probable yields of coke, tar and gas on carbonization of these coals in the full-scale plant installed at the Institute have been estimated[4] and

TABLE 2—YIELD OF PRODUCTS FROM LOW TEMPERATURE CARBONIZATION OF SOME INDIAN COALS TESTED

(all figures as yields per ton of dry coal)

Source of coals	Raniganj field (West Bengal)				B.R.K. field (Bihar)	M.P. and Maharashtra	Assam
B.S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
I *Gray-King assay at* 600°C.							
Coke, cwt	14·3-14·7	15·0-15·2	14·2-16·5	14·6 -14·9	15·2-16·0	15·0-15·3	12·8-13·1
Tar, gal.	26·0-29·1	22·6-23·7	17·2-31·8	27·5 -27·6	19·5-22·4	19·0-20·8	41·2-43·7
Liquor, gal.	16·4-17·0	9·4-13·8	8·5-17·2	10·5 -12·5	11·2-13·9	14·3-15·2	9·6-11·1
Gas cu. ft at S.T.P.	3,300-3,515	3,206-3,223	2,961-3,622	3,400-3,547	2,653-3,447	3,093-3,339	4,123-4,478
Type of coke pencils obtained	B-C	B	B-E/F	E-F	A-C	A-A/B	G-G_2/G_3
II *Fischer assay at* 550°C.							
Coke, cwt	14·3-14·9	15·1-15·5	14·6-16·8	14·8 -15·2	15·5-16·4	14·9-15·8	13·2-13·4
Tar, gal.	23·1-25·9	20·4-22·2	14·3-29·5	27·3 -27·4	14·3-20·4	17·2-21·5	36·7-38·7
Liquor, gal.	11·0-14·3	11·6-14·0	4·5-14·0	9·2 -11·8	10·3-14·1	12·5-14·3	9·2-13·4
Gas spirit, gal.	1·3- 1·4	1·0- 1·1	0·9- 1·1	1·2 - 1·3	0·9- 1·2	1·0-1·2	1·2- 1·9
Gas, cu. ft	2,740-2,923	2,560-2,580	2,370-2,965	2,570-2,740	2,510-2,610	2,270-2,590	3,480-4,000
III *SIE tests at* 600°C.							
Coke, cwt	13·9-15·0	15·0-15·1	14·4-16·6	15·2 -15·5	15·1-16·2	14·5-14·6	13·5-14·0

(Contd.)

TABLE 2—*Contd.*

SOURCE OF COALS	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M.P. AND MAHARASHTRA	ASSAM
B.S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
Tar, gal.	11·2-15·7	12·1-13·2	10·1-17·5	15·9-17·0	8·1-13·5	9·6-11·9	15·7-19·5
Liquor, gal.	18·8-20·8	13·5-17·5	11·2-16·6	13·4 -18·4	11·7-15·7	16·1-23·5	13·4-17·9
Gas spirits, gal.	1·3- 1·5	1·1- 1·2	0·8- 1·4	1·1 - 2·2	0·6- 1·0	0·8- 1·6	1·7- 1·8
Gas, cu. ft	3,680-6,000	4,290-4,430	3,725-4,750	3,905-4,280	3,620-4,650	5,230-6,580	5,950-6,350
IV *Estimated yields from Continuous Vertical Retort installed at C.F.R.I.*							
Coke, cwt	14·3-14·7	15·0-15·2	14·2-16·4	14·6 -14·9	15·2-16·0	15·0-15·3	12·8-13·1
Tar, gal.	17·2-19·2	14·9-17·8	11·4-21·0	10·15-18·22	12·9-14·8	12·5-13·7	27·2-28·8
Gas, cu. ft	5,940-6,330	5,770-5,800	5,330-6,520	6,120-6,385	4,775-6,205	5,570-6,010	7,420-8,060

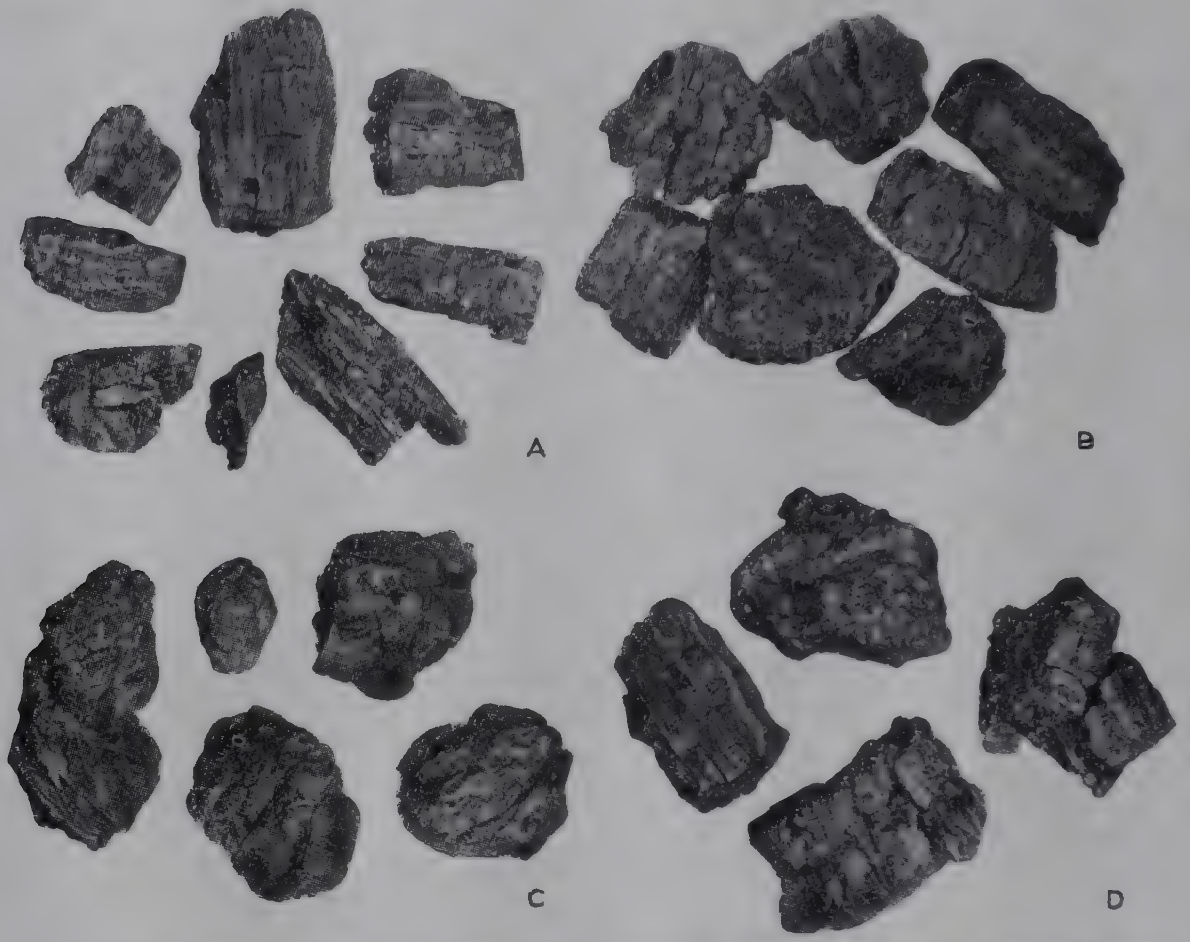

FIG. 4—COKE SAMPLES OBTAINED FROM SPO CARBONIZATION TESTS: (A) Jambad-Bowlah (Sankarpur colliery, Raniganj coalfield) (B) Taltore (Ikrah Nandi colliery, Raniganj coalfield) (C) Bharatchalk (Chinakuri colliery, Raniganj coalfield) (D) Koithee (Jamuria colliery, Raniganj coalfield)

summarized in Table 2. The overall range for the coals tested is likely to be as below:

	Raniganj, M. P. and B.R.K. coals	Assam coal
Coke, cwt	14·2[a] to 16·5[b]	*c* 13
Tar, gal.	11·5[c] to 21·0[a]	27 to 29
Gas, cu. ft	4775[d] to 6520[a]	7420 to 8020

(a) Low coke, and high tar and gas yields in the case of a very high volatile, low ash Raniganj coal;

(b) High coke yields for a medium volatile semicaking Raniganj coal and a medium volatile high ash B. R. K. coal;

(c) Low tar yields for the above mentioned Raniganj and B. R. K. coals, and the weathered M. P. coal samples;

(d) Low gas yield for the above mentioned Raniganj and B. R. K. coals.

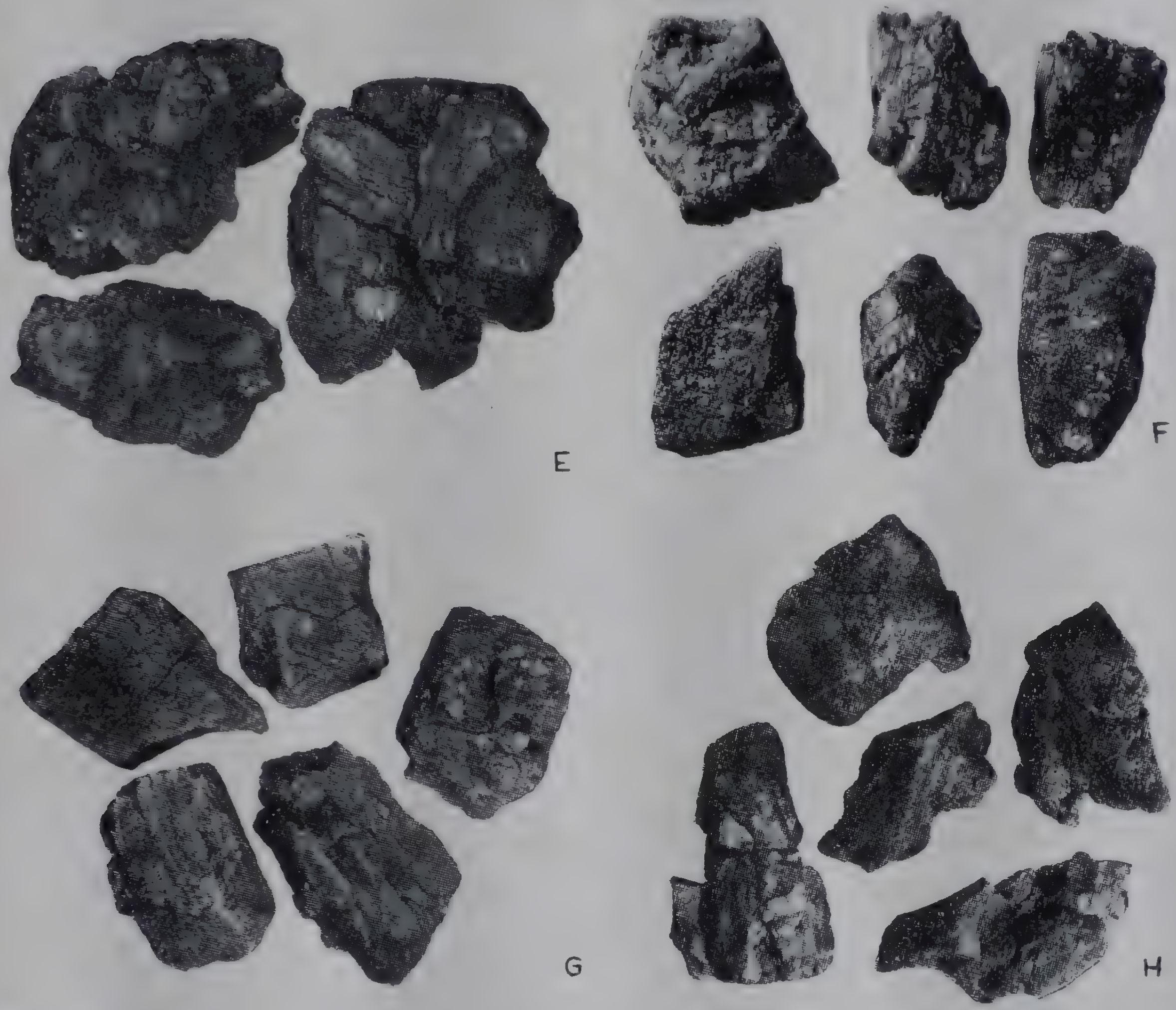

Fig. 4A—Coke samples obtained from SPO carbonization tests : (E) Raghunathbati (Dhemomain colliery, Raniganj coalfield) (F) Sirka (Bhurkhunda colliery, B. R. K. coalfields) (G) No. 3 Seam (Rawanware colliery, M. P.) (H) Tipong (Tipong colliery, Assam)

It has been observed that while the estimated coke yields more or less agree with the actual yields, in the plant tar yields are slightly on the higher side, and gas yields lower than the actual plant yields.

PROPERTIES OF THE COKES OBTAINED

The types of the coke pencils obtained from the coals tested in Gray-King assay varied from A (for a completely non-caking coal) to G_2/G_3 (for highly caking Assam coal). Both the Fischer and SPO cokes were subjected to screen, proximate and ultimate analyses and the bulk density and calorific values were also determined. In addition, the SPO cokes were subjected to physical tests, such as Shatter, Haven and B. S. Abrasion (Table 3). Apparent density, real density, porosity, critical air blast and reactivity values, and ignition point were also determined for some cokes.

The screen analyses of the cokes show that unlike the sized coal test charge in "SPO fixed bed carbonization", the charge in the Fischer rotary retort, suffers considerable disintegration into smaller sizes. This is due to

TABLE 3—PROPERTIES OF FISCHER AND SPO COKES

SOURCE OF COALS	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M.P. AND MAHARASHTRA	ASSAM
B.S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
			FISCHER COKES				
(i) Screen analysis of coke as discharged (% cum.)							
+1·5 in.	12·0 -24·09	43·9 -44·2	15·0 -38·6	29·9 -30·7	23·9 -35·9	27·4 -28·7	6·5- 43·9
+1·0 in.	50·0 -62·0	68·0 -73·9	38·9 -69·7	66·9 -69·9	60·9 -69·2	53·6 -62·4	39·0 -68·3
—0·5 in.	20·8 -22·4	14·4 -20·7	15·5 -27·9	13·3 -13·7	12·6 -20·3	19·1 -25·4	19·9 -36·1
(ii) Bulk density of coke as discharged, lb./cu. ft	22·0 -27·0	28·0 -30·9	24·5 -40·0	26·0 -26·5	23·9 -29·2	. .	20·5 -27·5
(iii) Proximate analysis, air-dried basis, %							
Moisture	1·3 - 3·1	4·2 - 4·3	2·5 - 4·8	3·5 - 4·4	2·4 - 2·8	1·4 - 2·3	0·9 - 2·6
Ash	19·9 -27·0	24·1 -31·5	22·3 -30·7	21·3 -30·2	26·5 -37·9	22·6 -24·6	5·2 - 8·8
Volatile matter	8·2 -10·9	8·4 -9·1	7·4 - 9·8	9·3 - 9·5	7.3 - 9·2	8·6 -12·4	8·7 - 9·8
(iv) Ultimate analysis, air-dried basis, %							
Carbon	63·97-68·35	57·60-64·58	58·18-65·65	58·32-66·30	53·33-62·46	62·61-67·98	78·64-84·40
Hydrogen	2·13- 2·23	1·90- 2·00	2·00- 2·24	2·08- 2·24	1·84- 2·29	2·21- 2·40	2·49- 2·70
Sulphur	0·25- 0·41	0·32- 0·33	0·26- 0·57	0·38- 0·78	0·38- 0·52	0·55- 0·62	1·84- 4·34
(v) Calorific value, airdried basis, Btu/lb.	10,430-11,290	9,340-10,430	9,520-10,710	9,650-11,120	8,590-10,260	10,410-11,350	13,010-13,520

(Contd.)

TABLE 3—*Contd.*

Source of coals	Raniganj (West Bengal)				B.R.K. field (Bihar)	M.P. and Maharashtra	Assam
B.S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
			SPO COKES				
(i) Screen analysis as discharged (% cum.)							
+1·5 in.	55·8 -59·0	69·7 -72·3	73·4 -86·8	87·2 -88·4	59·5 -72·4	29·3 -54·6	70·5 -89·2
+1·0 in.	79·4 -86·3	87·8 -88·0	87·0 -93·7	94·5 -95·2	80·7 -93·1	56·9 -86·0	87·2 -93·5
—0·5 in.	6·2 -10·4	6·1 - 8·0	3·4 - 7·3	2·2 - 3·0	2·3 - 7·6	7·6 -16·3	4·2 - 5·9
(ii) Bulk density (lb./cu. ft)	32·8 -35·7	31·9 -35·5	26·1 -35·3	33·0 -33·3	33·1 -36·3	32·9 -37·3	20·5 -26·6
(iii) Proximate analysis, air-dried basis, %							
Moisture	1·6 - 5·0	1·7 - 2·0	2·1 - 3·9	3·6 - 4·6	3·0 - 3·7	1·0 - 2·5	1·0 - 2·9
Ash	20·0 -25·6	24·3 -30·8	19·8 -29·0	19·8 -28·1	27·0 -35·8	22·0- 31·8	8·5 - 9·3
Volatile matter	5·1 - 8·9	5·9 - 6·1	4·3 - 9·1	8·1 - 9·6	5·8 - 6·9	3·4 - 6·0	6·5 - 7·3
(vi) Ultimate analysis, air-dried basis, %							
Carbon	65·37-69·64	61·91-67·95	60·54-71·06	61·78-68·30	55·38-62·99	64·53-71·00	77·93-81·83
Hydrogen	1·55- 1·97	1·61- 1·70	1·59- 2·10	1·98- 2·10	1·42- 1·99	1·28- 1·68	2·17- 2·43
Sulphur	0·23- 0·34	0·47- 0·51	0·19- 0·32	0·30- 0·34	0·42- 0·55	0·50- 1·42	2·22- 4·88
(v) Calorific value, airdried basis, Btu/lb.	10,310-11,010	9,950-10,880	9,880-11,460	9,990-11,020	9,840-10,100	10,020-11,400	12,880-13,510

(Contd.)

TABLE 3—*Contd.*

Source of coals	Raniganj field (West Bengal)				B.R.K. field (Bihar)	M.P. and Maharashtra	Assam
B.S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
(vi) Shatter test on coke (4 drops % cum.)							
+1·5 in.	30·8 -45·2	51·4 -54·4	59·8 -78·2	65·5 -69·2	49·0 -63·8	19·4 -31·2	50·0 -71·0
+1·0 in.	68·6 -75·0	75·6 -81·2	80·8 -91·1	86·5 -89·4	78·1 -87·6	56·4 -74·6	77·2 -88·5
—0·5 in.	86·4 -89·5	88·2 -91·6	90·8 -95·4	93·7 -95·4	91·2 -95·2	85·1 -92·4	94·0 -95·5
(vii) Haven test on +1 in., 100 rev.	43·5	54·1 -61·0	59·0 -76·8	67·2 -74·1	54·2 -72·9	30·2 -46·5	51·2 -73 0
+1 in. Stability Factor 200 rev.	32·4	42·7 -49·1	47·1 -68·0	56·2 -63·0	42·0 -63·6	20·1 -35·0	41·1 -64·6
(viii) B. S. Abrasion test on +1 in. coke, +1/8 in. abrasion index	62·5 -64·4	58·3 -59·7	58·0 -65·9	60·5 -61·1	65·5 -66·7	..	61·7 -63·9

TABLE 4—PROPERTIES OF SPO TARS

(all results on dry tar basis)

SOURCE OF COALS	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M.P. AND MAHARASHTRA	ASSAM
B. S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
Sp. gr.	1·04- 1·06	1·01- 1·03	1·01- 1·03	1·03- 1·04	1·04- 1·05	1·01- 1·04	1·03- 1·05
Total solids insoluble in toluene, %	2·34- 3·02	1·43- 2·11	0·79- 2·96	0·83- 1·73	1·96- 2·41	..	1·56- 2·54
Distillation, % oils up to 360°C.	68·2 -73·3	63·9 -65·4	57·4 -74·2	72·2 -78·1	59·4 -64·3	59·0 -64·3	62·4 -67·6
Residue (Pitch)	25·7 -30·0	31·7 -33·5	24·9 -40·8	21·1 -26·8	34·3 -39·4	34·8 -40·1	30·9 -36·3
Fractional distillation of tar oils up to 360°C., % Up to 170°C.	3·4 - 5·1	1·6 - 2·4	1·3 - 4·0	2·9 - 3·0	1·2 - 2·8	1·8 -5·5	2·8 - 3·0
170°-230°C.	20·9 -26·7	18 0 -18·5	15·5 -23·5	20·0 -22·8	17·0 -20 0	13·4 -17·1	19·1 -23·1
230°-270°C.	10·4 -15·5	14·3 -14·5	10·2 -18·0	17·0 -17·2	12·0 -13·1	10·3 -12·9	10·6 -11 5
270°-360°C.	26·4 -32·2	30·0 -30·0	28·5 -33·5	32·0 -35·4	25·3 -32·1	29·8 -32·1	28·3 -32·2
Composition of tar oils upto 360°C. (% of dry tar) Tar acids	15·8 -24·4	15·5 -27·7	14·5 -28·4	22·0 -27·2	18·7 -23·1	15·3 -21·1	21·5 -24·0
Tar bases	2·0 - 2·8	2·4 - 2·5	1·7 - 2·9	2·7 - 3·5	2·9 - 3·2	2·0 - 3·6	3·3 - 3·4
Neutral oils	44·6 -54·7	35·3 -45·8	35·3 -44·4	47·4 -47·5	36·0 - 38·3	40·1 -42·4	35·1 -42·7
Fractional distillation of tar acids, % Phenols, upto 185°C.	0·8 - 1·0	0·8 - 1·2	0·4 - 2·4	1·1 - 1·2	0·7 - 1·4	0·7 -2·5	1·5 - 1·7

(Contd.)

TABLE 4—*Contd.*

Source of coals	Raniganj field (West Bengal)				B.R.K. field (Bihar)	M.P. and Maharashtra	Assam
B. S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
Cresols, 185°-205°C.	12·8 -18·0	7·8 -12·6	7·7 -15·8	8·4 - 9·2	7·6 -14·2	6·1 - 7·5	15·2 -23·8
Xylenols, 205°-215°C.	14·9 -15·5	9·5 -10·8	7·9 -17·4	16·4 -17·7	19·4 -23·2	10·4 -16·6	11·7 -16·7
Tar acids boiling upto 215°C.	28·5 -34·5	18·1 -24·6	17·9 -29·9	26·7 -27·3	26·4 -34·9	18·4 -23·4	33·4 -40·6
Fractional distillation of neutral oils, %							
Light oils, up to 195°C.	8·0 -10·0	13·8 -15·0	11·1 -15·7	11·7 -15·8	9·0 -14·0	8·1 -18·1	12·0 -12·3
Middle oils, 195°-270°C.	32·0 -41·0	29·3 -34·6	27·7 -35·4	28·7 -32·2	28·0 -35·6	25·5 -35·6	31·9 -36·0
Heavy oils, 270°-360°C.	44·5 -48·0	43·7 -44·5	42·8 -49·4	44·4 -46·3	40·6 -45·2	37·3 -46·5	40·0 -42·6
Ultimate analysis of dry tar, %							
Carbon	82·71-84·56	83·50-83·80	83·11-86·03	84·12-84·14	83·66-85·10	83·76-84·52	82·93-84·72
Hydrogen	7·60- 8·55	8·41- 8·46	8·16- 8·84	8·32- 8·46	7·67- 8·12	7·30- 7·90	7·05- 7·96
Sulphur	0·24- 0·33	0·37- 0·39	0·32- 0·40	0·37- 0·44	0·69- 0·73	1·40- 2·79	1·06- 3·23
Nitrogen	1·22- 1·32	1·25- 1·28	1·06- 1·40	1·10- 1·35	1·05- 1·10	0·92- 0·93	0·64- 0·83
Oxygen (by diff.)	6·04- 7·81	6·09- 6·18	4·35- 6·91	5·67- 5·85	5·36- 5·98	4·52- 5·04	5·37- 6·98
Calorific value, Btu/lb.	15,690-16,610	16,230-16,380	16,070-16,800	16,470-16,550	16,260-16,400	16,010-16,540	15,820-16,450

TABLE 4A—PROPERTIES OF FISCHER TARS

(all results on dry tar basis)

SOURCE OF COALS	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M.P. AND MAHARASHTRA	ASSAM
B. S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
Sp. gr.	1·02- 1·03	1·03- 1·04	1·02- 1·03	1·01- 1·01	1·01- 1·04	1·00- 1·03	0·96- 1·03
Total solids insoluble in toluene, %	3·12- 4·22	2·59- 3·66	1·46- 3·63	0·66- 0·96	1·72- 1·83	..	1·20- 1·40
Distillation, %							
Oils upto 360°C.	63·2 -69·0	64·1 -66·2	48·7 -68·0	62·1 -63·2	55·6 -62·6	56·2 -63·0	58·3 -59·8
Residue (pitch)	30·0 -35·6	32·3 -35·3	28·9 -49·9	36·1 -37·2	35·6 -43·0	35·6 -42·4	38·4 -40·3
Fractional distillation of tar oils up to 360°C.,%							
Upto 170°C.	1·6 - 3·9	2·5 - 2·6	1·5 - 3·3	3·3 - 4·0	2·0 - 2·5	3·4 - 5·4	1·3 - 3·9
170°-230°C.	12·4 -15·9	13·7 -13·7	10·6 -15·1	13·6 -16·0	12·8 -13·8	11·8 -16·4	12·2 -14·3
230°-270°C.	11·2 -12·5	14·2 -14·5	9·6 -15·1	10·3 -12·4	10·8 -13·4	10.0 -12·5	10·9 -12·1
270°-360°C.	36·7 -38·0	33·7 -35·4	25·9 -38·5	32·5 -33·2	27·4 -36·0	27·6 -33·2	30·6 -33·3
Composition of tar oils upto 360°C.							
Tar acids	14·7 -24·1	28·5 -28·6	6·8 -28·9	21·8 -23·4	17·8 -24·7	17·5 -19·3	17·1 -20·6
Tar bases	1·6 - 2·0	2·4 - 3·0	1·2 - 3·3	1·9 - 2·4	2·9 - 3·4	2·4 - 3·7	3·3 - 3·9
Neutral oils	40·4 -46·9	32·6 -35·2	32·5 -40·7	37·9 -37·9	27·8 -41·9	34·5 -39·4	35·1 -38·6

(Contd.)

TABLE 4A—*Contd.*

SOURCE OF COALS	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M.P. AND MAHARASHTRA	ASSAM
B. S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
Fractional distillation of tar acids, %							
Phenol, upto 185°C.	1·0	1·2 - 1·2	0·5 - 1·5	0·6 - 1·0	0·5 - 1·7	1·0 - 2·0	0·7 - 1·4
Cresols, 185°-205°C.	6·0	3·0 - 6·8	1·5 -10·5	5·2 - 6·4	5·9 - 7·2	3·0 - 8·3	6·3 -10·3
Xylenols, 205°-215°C.	8·0	6·5 - 7·6	2·5 - 9·3	8·0 -12·0	8·3 -16·2	7·2 - 8·3	11·2 -14·5
Tar acids boiling up to 215°C.	15·0	10·7 -15·6	6·5 -21·3	13·8 -19·4	15·9 -23·8	12·2 -17·6	19·5 -23·7
Fractional distillation of neutral oils, %							
Light oils, upto 195°C.	9·5	9·5 -11·2	9·3 -15·0	12·3 -15·0	8·2 -13·3	10·2 -14·5	7·6 -11·7
Middle oils, 195°-270°C.	26·5	28·0 -31·0	26·4 -33·0	26·6 -27·1	23·3 -28·9	28·5 -35 0	29·3 -33·1
Heavy oils, 270°-360°C.	50·5	44·0 - 44·5	43·4 -53·2	42·1 -49 2	37·8 -50·6	38·9 -43 0	41·6 -45 9
Ultimate analysis of dry tar, %							
Carbon	82·45-83·06	82·69-82·87	83·20-87·06	83·44-83·51	82·11-83·11	83·66-84·25	82·41-84·18
Hydrogen	8·92- 9·12	8·73- 8·78	8·45- 8·93	8·78- 8·92	8·10- 8·20	9·19- 9·23	8·43- 9·24
Sulphur	0·19- 0·29	0·30- 0·31	0·28- 0 35	0·16- 0·29	0·79- 0·97	0·43- 0·44	1·27- 3·09
Nitrogen	0·99- 1·29	1·19- 1·40	0·97- 1·46	1·34- 1·38	0·82- 1·09	0·88- 0·97	0·41- 0·69
Oxygen (by diff.)	6·43- 7·06	6·78- 6·88	3·00- 6·48	5·86- 6·24	6·12- 7·25	5·02- 5·79	4·65- 4·31
Calorific value, Btu/lb.	16,390-16,540	16,450-16,510	16,320-17,320	16,630-16,650	16,010-16,440	16,850-16,900	16,380-17,070

TABLE 5—PROPERTIES OF LIQUOR FROM FISCHER AND SPO TESTS
(all values as p.p.m.)

SOURCE OF COALS	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M.P. AND MAHARASHTRA	ASSAM
B.S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
			Liquor samples from Fischer assays				
Free NH_3	8,930- 9,890	3,275- 4,150	4,633-10,421	10,120	1,496- 1,842	440- 1,836	747- 1,042
Fixed NH_3	500- 910	987-11,890	785- 1,335	722	340- 780	647- 970	360- 4,614
Total NH_3	9,430-10,700	5,137-15,165	5,710-11,756	10,842	1,836- 2,386	1,087- 2,806	1,402- 5,361
Phenol	5,010- 7,500	3,050- 3,701	3,242- 4,350	2,948	1,298- 1,654	1,389- 1,860	1,019- 5,845
Thiocynate	1,390- 1,730	..	1,129- 1,435	1,092	..	..	..
Cyanide	210- 250	180- 185	120- 286	186	82- 90	77- 93	104- 185
Sulphide	540- 1,110	28- 30	27- 712	492	75- 91	385- 421	446- 4,224
C/A value p.p.m.	12,200-16,700	..	..	..	..	..	..
			Liquor samples from SPO tests				
Free NH_3	9,080-11,110	6,880-12,440	6,240-16,280	10,230-11,692	1,667- 2,000	697- 6,141	1,649- 8,464
Fixed NH_3	790- 1,860	680- 784	320- 1,198	636- 802	681- 1,020	617- 797	884-12,066
Total NH_3	10,600-12,970	7,644-13,120	6,732-16,960	11,032-12,328	2,348- 2,992	1,494- 6,758	2,533-13,989
Phenol	7,000- 9,000	1,932- 7,262	1,348- 4,241	3,214- 3,510	1,305- 1,732	1,035- 1,243	2,063- 4,905
Thiocynate	1,267- 1,375	..	1,394- 1,614	1,210- 1,241	..	..	..
Cyanide	240- 350	196-	40- 310	204- 210	80- 95	59- 72	56- 158
Sulphide	508- 648	40- 240	47- 682	486- 590	75- 140	68- 337	190- 2,112
O/A value	11,180-13,214	..	..	..	..	..	..

TABLE 6—ANALYSES OF AVERAGE GAS SAMPLES FROM FISCHER AND SPO TESTS

(all values as vol. %)

SOURCE OF COALS	RANIGANJ FIELD (West Bengal)				B.R.K. FIELD (Bihar)	M. P. AND MAHARASHTRA	ASSAM
B.S. Caking Index of coals	less than 3	2-3	5-10	15	3-5	less than 3	20-21
			FISCHER ASSAYS				
CO_2	10·3-13·4	9·8-11·0	6·9-12·6	6·0-11·0	12·0-18·0	9·4-24·0	11·0-14·4
CnHm	4·1- 5·3	3·0- 3·6	2·0- 4·8	4·0- 4·1	2·0- 3·4	2·6- 4·8	4·4- 5·2
O_2	0·3- 0·4	0·3- 0·4	0·2- 0·6	0·4- 0·8	0·4- 1·0	0·4- 0·8	0·4- 0·6
CO	9·1-10·6	9·0-11·1	5·3-10·6	8·0- 8·8	6·8- 9·0	8·0- 9·8	5·8- 6·2
CH_4	53·3-57·8	51·8-56·0	54·9-59·8	58·0-60·0	46·2-50·7	47·1-53·0	58·2-61·2
H_2	14·5-17·8	18·5-21·2	12·8-26·5	13·3-19·6	21·0-23·6	11·5-23·5	10·0-14·4
N_2	0·6- 2·5	1·5- 1·8	0·6- 2·6	2·0- 4·0	1·4- 4·8	1·0- 3·9	1·2- 5·6
Gross calorific value, Btu/cu. ft	702-747	692-718	698-760	746-751	589-673	544-670	722-776
			SPO TESTS				
CO_2	7·0-10·2	6·0- 8·0	6·0- 8·0	5·0- 7·5	10·6-12·7	4·6-12·8	6·2-10·1
CnHm	3·7- 5·2	3·5- 4·0	2·2- 5·2	5·8- 5·8	3·6- 7·2	1·8- 5·6	7·6- 8·4
O_2	0·4- 0·5	0·2- 0·4	0·2- 1·5	0·5- 0·6	0·2- 1·0	0·4- 0·8	0·6- 1·0
CO	8·1-10·0	7·8- 8·9	5·7- 8·4	6·5- 7·6	5·6- 7·8	9·5-11·2	5·1- 7·0
CH_4	41·0-58·8	49·0-49·2	45·7-63·5	58·5-60·5	45·6-58·5	32·3-57·1	48·6-53·5
H_2	17·4-34·0	30·0-30·4	15·5-39·1	18·4- 9·4	19·1-28·7	17·9-40·4	19·7-25·6
N_2	1·3- 4·1	0·8- 1·8	0·5- 3·7	0·8- 3·0	0·9- 2·5	4·3- 4·4	0·8- 6·2
Gross calorific value, Btu/cu. ft	614-744	680-692	642-772	784-799	643-759	522-765	735-787

inherent difference in the two carbonizing methods. Whereas +1 in. and −0·5 in. size fractions in SPO cokes varied from 57 to 95 and 2 to 16 per cent respectively, the +1 in. and −0·5 in. fractions in Fischer cokes varied from 40 to 74 and 13 to 36 per cent respectively. SPO cokes on the whole had a higher bulk density than Fischer cokes, the exceptions being Salanpur and an Assam coke. The volatile matter contents of cokes from Fischer assay and SPO varied from 7·3 to 12·4 and 4·0 to 9·5 per cent respectively. The moisture content of cokes was less than 5 per cent and the ash contents varied over a wide range from 5·2 per cent coke from Assam coal to 37·9 per cent for coke from B. R. K. Carbon content on air-dried basis ranged from 53·3 to 71·1 per cent except for Assam coke. Sulphur was less than 0·8 per cent except in one M. P. coke. Assam coke had a higher percentage of carbon (78·0-84·4) and sulphur (1·8-4·3). Hydrogen content of all cokes was of the order of 1·3-2·7 per cent. Calorific value of the coke samples from SPO and Fischer assays varied from 9,850 to 11,450 and 8,600 to 11,350 Btu/lb. respectively, except Assam coke which showed 12,900 to 13,500 Btu/lb. The differences in percentages of carbon, sulphur and ash as stated above for the two groups of cokes explain the difference in the calorific values (Table 3). The physical tests on SPO cokes showed that the cokes were of satisfactory strength required for domestic cokes. The M. P. cokes gave lower values in physical tests. This might be due to effect of weathering on the coal samples tested. The +1 in. and +0·5 in. shatter values generally ranged from 70 to 90 per cent and 85 to 96 per cent respectively showing that the cokes possess sufficient impact hardness for household purpose. The +1 in. Haven values for 100 and 200 revolutions varied from 43 to 77 and 32 to 68 per cent respectively, except for M. P. cokes. The abradability characteristics of cokes were quite satisfactory, as shown by the +1/8 in. B. S. abrasion indices which varied from 58 to 87 per cent.

Fig. 4 and 4A(A-H) show photographs of typical coke samples obtained from SPO tests. It is seen that highly caking coals show a tendency to agglomerate and form larger sizes of cokes as is apparent from the photographs of cokes from Assam coals and Raghunathbati seam coal from Raniganj field.

PROPERTIES OF THE TARS OBTAINED

The dry tars obtained from SPO and Fischer tests were subjected to detailed analysis according to standard methods. Tables 4 and 4A summarize the properties of SPO and Fischer tars respectively.

The dry SPO tars were found to be slightly higher in specific gravity than the Fischer tars, the range for both being 0·96 to 1·06. The content of total solids insoluble in toluene in both SPO and Fischer tars ranged from 0·8 to 4·2 per cent. The Fischer tars are more primary in nature than the SPO tars. The latter contain a higher percentage of oils and a lower percentage of pitch residue than the Fischer tars. The fractional distillation of tar oils, tar acids and neutral oils also show that SPO tars are less primary in nature. The difference between the properties of the two types of tars also justify the observation made earlier that tar vapours are more subjected to cracking in SPO than in the Fischer retort.

PROPERTIES OF THE OTHER BYPRODUCTS

The analyses of liquor from both SPO and Fischer tests are given in Table 5 and data for the gases in Table 6. The total ammonia and phenol contents of the SPO liquor samples varied from 1,500 to 16,960 and from 1,040 to 9,000 p.p.m. respectively, the corresponding figures for the Fischer liquor samples being 1,090 to 15,170 and from 1,020 to 7,500 p.p.m. respectively.

The main features of the semi-pilot and Fischer gases are given below:

Particulars	Gases from SPO	Gases from Fischer assay
Methane, %	32·3—63·5	46·2—61·2
Hydrogen, %	15·5—40·4	10·8—26·5
Calorific value, Btu/cu. ft	522—799	544—776

The low calorific values of the gases from M. P. coals and their lower methane and higher carbon dioxide and hydrogen contents show that these coals had suffered considerable weathering. The hydrogen sulphide content of gases from Assam and B. R. K. coals were also determined. The figures for gases obtained in SPO tests from Assam coals varied from 2,090 to 5,000 grains per 100 cu.ft.

The composition of gas spirits obtained from both SPO and Fischer tests were also determined[5].

Composition	SPO	Fischer assay
Aromatics, %	58—78	56—76
Olefins, %	10—26	12—32
Paraffins, %	4—20	4—20

The ultimate analysis and calorific values of a few samples of gas spirits were also determined to ascertain how the data compare with those of tars and tar neutral oils.

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A Process for Obtaining Moulded Shapes from Sub-standard Fuels for Use as Domestic Fuel or Metallurgical Coke

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The process mainly comprises of flash heating the slack coal in a fluidized bed to a critical temperature, extrusion and subsequent carbonization at 600 or 750°C. The shapes obtained at 600°C. are more reactive than low temperature coke obtained by conventional methods, and can be used as domestic fuel. Those obtained at 750°C. have sufficient strength to be used as metallurgical coke. The results obtained with Koithi, Poniati, Dishergarh, Zero seam and Jambad-Bowlah coals are presented in the paper.

Metallurgical coke suitable for blast furnace can be obtained only from coking coals by the conventional process. The major portion of India's coal resources consists of weakly caking or completely non-caking types. The lack of adequate resources of coking coals is the main bottleneck in the further expansion of the iron and steel industry.

Kramers *et al.*[1] have shown that the swelling and agglutinating power of very weakly caking coals of high or low volatile matter content can be considerably enhanced by rapid carbonization in thin layers or beds. The cokes obtained by employing a heating rate of 200°C./min. near the wall and 10 to 40°C./min. at the centre were comparable in strength to a gas or low temperature coke. Dulhunty and Harrison[2] found that with a rate of heating of 140°C./min. a low rank bituminous coal yielded a residue of "medium" strength. On the other hand, a medium rank bituminous coking coal, which yields a strong coke at the usual rate of heating found in standard practice gave a non-coherent residue or char, the particles of which had not softened or rounded, by extending the time required to reach 700°C. to 144 hours (approximate heating rate of 0·06°C./min.). Certain "weakly coking" coals yield strong cokes by rapid carbonization, heating at a rate of about 5°C./min. or greater. The evidence is not sufficiently conclusive to indicate the definite range of coals which may be benefited by rapid carbonization. The indications are that coals with B. S. swelling numbers 1 to 3 are likely to respond to such treatments[3]. But the amount of coal that can be so treated in a single charge is restricted on account of the low rate of heat transfer through the charge owing to the low thermal conductivity of coal. Since the beneficial effects of rapid carbonization are largely confined to temperatures up to the softening point of the coal, Jappelt[4] has reported a two-stage process for the manufacture of metallurgical coke and domestic smokeless fuel from weakly caking or non-coking coals. Rapidly preheated coal (in cyclone type of heater) was fed into the conventional coke ovens for formation of metallurgical coke. Preliminary experiments carried out on Indian coals at this Institute could not confirm Jappelt's claims.

Sapoznikov[5] has developed a new technique for the moulding of coal for production of metallurgical coke from weakly caking and noncoking coals. Strong coke of large size can be obtained from all types of coals including gas coals and poorly caking coals provided they are rapidly heated to their softening temperature and the plastic mass thus formed is moulded into a monolithic mass and carbonized under controlled rates of heating—the nature of heating and the time of treatment required depending upon the nature of coke desired. Slow rates of heating are employed for producing large-sized metallurgical cokes and rapid rates for production of coke for domestic or industrial purposes or for gasification. Most of the experiments reported by Sapoznikov have been done on a 50 kg./hr capacity experimental plant, but a 400 ton/day capacity plant is now in operation at Kharkov. The importance attached to this process in the U.S.S.R. can be gauged from the fact that about 100 million tons per year of coal will be treated by this technique to produce 70·5 million tons of coke, of which 66 million tons can be used for power and metallurgical purposes and 4·5 million tons for chemical purposes. In addition, 1·8 million tons of benzene and 40×10^9 cubic meters of gas[6] are also obtained as byproducts.

Apart from using weakly caking coals, the other advantages claimed for the process are removal of primary tar from the system at 500°C. production of a very reactive coke (said to be 10 times more reactive than normal

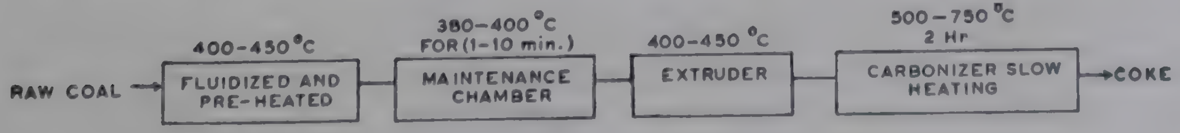

Fig. 1—Flowsheet of the process of extrusion and carbonization of coal

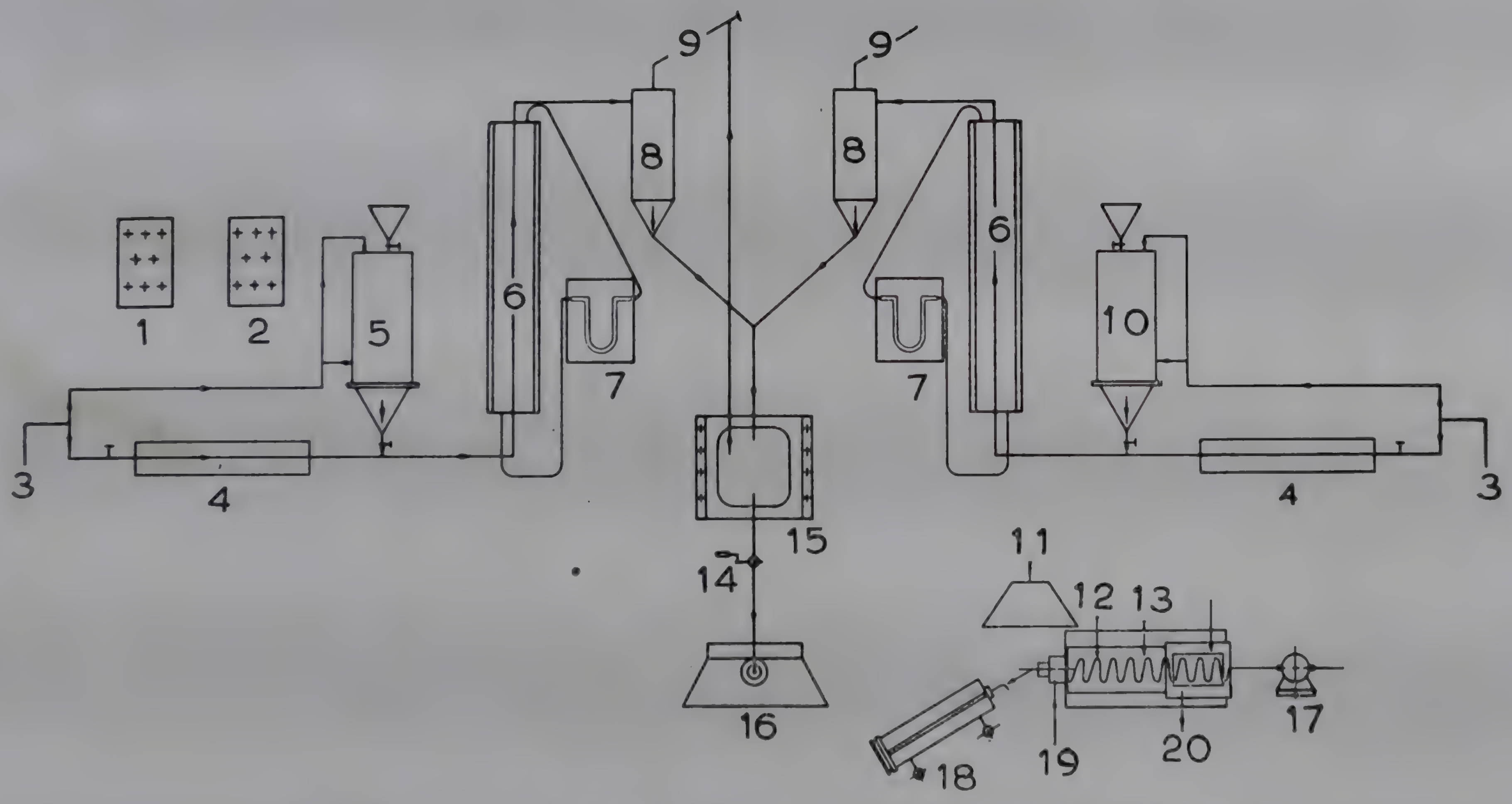
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Fig. 2—Flowsheet of the semi-pilot plant for the extrusion of coal: (1) Control panel I (2) Control panel II (3) Nitrogen (4) Preheater (5) Coal bunker (6) Vertical heating column (7) Manometer (8) Cyclone (9) Exit (10) Coal bunker (11) To exhaust (12) Screen press (13) Heating zone (14) Feeding control (15) Maintenance tube furnace (16) Extruder section (17) Motor (18) Carbonizer (19) Die (20) Cooling

coke) and production of moulded shapes suitable for metallurgical use at temperatures below 750°C. The reactive coke produced could be gasified in 10–15 min. instead of the usual 4–5 hr. Also use of such moulded and uniformly sized reactive coke in the blast furnace results in increased capacities and quicker reduction of the ore. It is believed that use of this coke in low shaft furnace results in a 20-fold increase in metal production compared to normal cokes and could also lead to a combination of metallurgical operation with production of synthesis gas for oils and chemicals. This paper describes the adoption of the Sapoznikov technique (with suitable modification) to Indian coals.

EXPERIMENTAL

The flowsheet of the process adopted is shown in Fig. 1. Fig. 2 shows the flow diagram of the apparatus used and Figs. 3, 3A and 3B the photographs of the apparatus. Coal crushed to −25 +52 mesh B.S.S. is dried and rapidly heated to a temperature below its softening point in an electrically heated

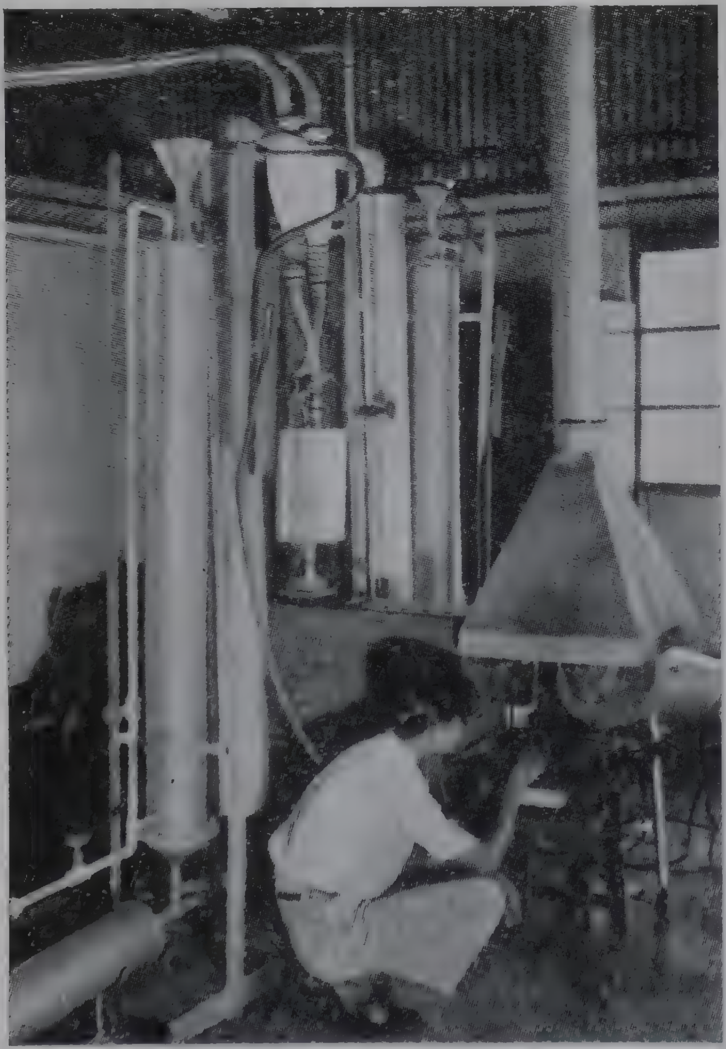

FIG. 3—APPARATUS FOR PREHEATING OF COAL

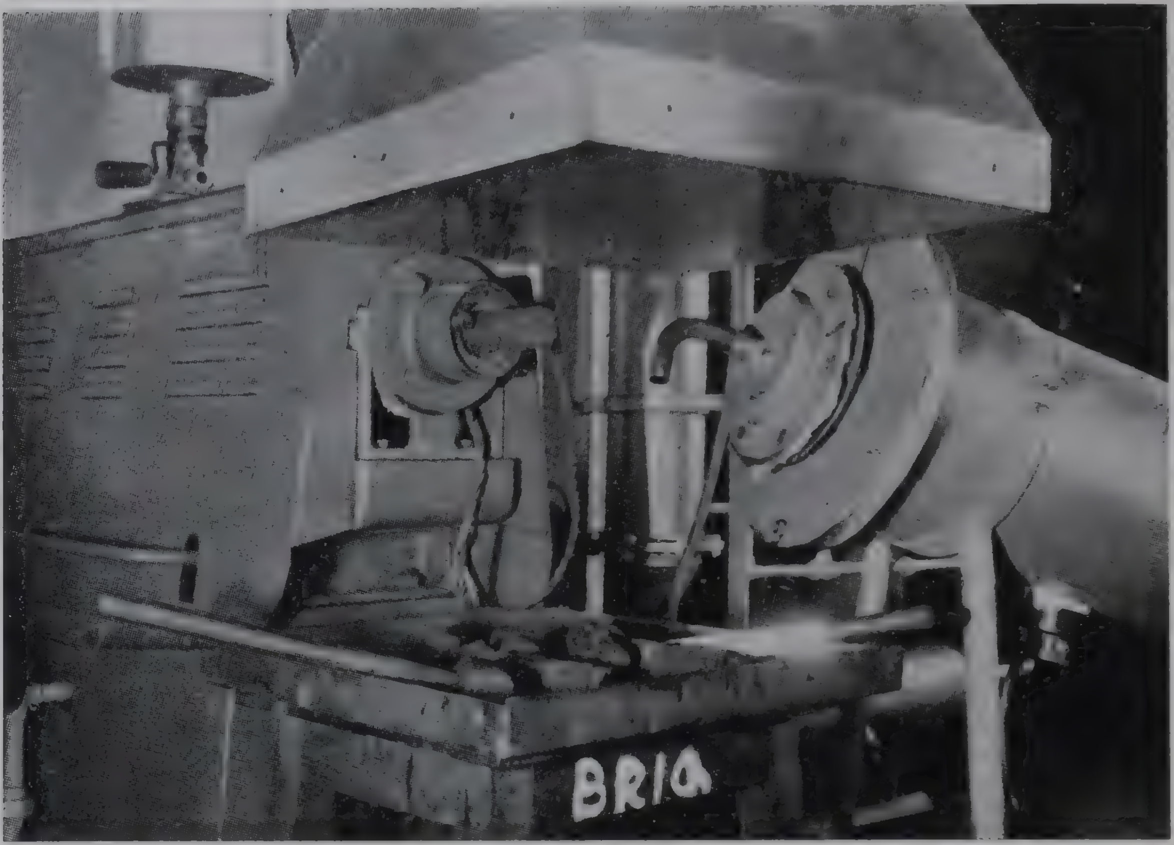

FIG. 3A—EXTRUSION AND CARBONIZATION UNIT

fluidized preheater causing partial devolatilization of the coal. The preheated coal is then maintained at a suitable temperature (380°-400°C.) in a chamber for 1-10 min. depending upon the nature of coal, and fed into an electrically heated extruder, maintained at 400°-450°C. The extrudes of different shapes are then slowly carbonized at 500°-750°C. For production of domestic fuel a carbonization temperature of 500°C. is sufficient, while for metallurgical coke it is necessary to carbonize at 750°C. the total time required being 0·5 hr and 2·5 hr respectively for the two processes. By this method it is possible to obtain fuel of uniform porosity. Fig. 4A shows the green extrudes and Fig. 4B some of the carbonized extrudes.

RESULTS AND DISCUSSION

Coals ranging in caking index from 3 to 18 were used in these investigations. Four sets of blends, two of Dishergarh-Jambad-Bowlah and two of Poniati-Jambad-Bowlah were also tried. A coking coal (Sendra coal) was studied to obtain comparative data. Table 1 gives the analysis of coals and blends used and Table 2 the analysis of extrudes carbonized at 600°C. and 700-750° C. The green extrudes have a volatile matter 8-14 per cent less than the original coals and the extrudes carbonized at 600°C. have 7-12 per cent volatile matter similar to smokeless fuels and the high temperature

TABLE 1—ANALYSES OF COALS USED IN EXTRUSION EXPERIMENTS

PARTICULARS	MOISTURE %	ASH %	V.M. %	F.C. %	CAKING INDEX
1. Dishergarh (Chinakuri)	2·2	12·9	35·6	49·3	18
2. Jambad-Bowlah (Jaipuria Kajora)	6·7	10·9	35·6	46·8	3
3. 50% Dishergarh and 50% Jambad-Bowlah	2·6	9·2	36·3	51·9	7
4. 70% Dishergarh and 30% Jambad-Bowlah	2·4	9·4	36·1	52·1	10
5. Poniati (East Baraboni)	2·5	10·5	36·0	51·0	10-11
6. 90% Poniati and 10% Jambad-Bowlah	2·8	10·8	35·7	50·7	9
7. 80% Poniati and 20% Jambad-Bowlah	2·9	10·9	35·6	50·6	7
8. Koithee (Jamuria)	2·6	17·7	31·0	48·7	10
9. Sendra (XIII and XIV Jharia)	1·0	16·0	21·0	62·0	15-16
10. Zero seam (Jharia)	0·5	18·2	17·5	63·8	8

extrudes 3·5-6·5 per cent similar to metallurgical coke. The ash in the high temperature moulded shapes never exceeded 23 per cent and was thus well within the range stipulated for metallurgical cokes.

The shatter index was obtained by taking 5 lb. of samples of size 1-2 in. and dropping it four times from a height of 6 ft on to a metallic plate and screening the products through 1·5 in., 1 in., 0·5 in. square sieves. The results are presented in Table 3. For comparison the shatter index of a metallurgical coke obtained in the coke oven is also given. The shatter index (per cent on 0·5 in.) of the moulded coke obtained at 600°C. varies from 91-96 per cent and shows only slight improvement on carbonization at 700°-750°C.

The Haven stability factor was obtained by tumbling 2·5 lb. of the sample of size 1-2 in. for 1500 revolutions at 25 r.p.m. in the standard apparatus (Table 4). This test gave results comparable with those obtained using 22 lb. sample and according to standard specification (Table 5). Therefore in all subsequent experiments the Haven index was obtained with 2·5 lb. sample. The Haven index obtained varied from 43-57 and the results indicate that products comparable in strength to metallurgical coke can be obtained from weakly caking coals and blends of weakly caking and non-coking coals under the conditions used. Similar results are obtained from low volatile bituminous coals (V. M. 18 per cent).

Reactivity measurements employing the C.A.B. tests[7] gave results ranging from 0·0100 to 0·0114 cu. ft/min. for extrudes carbonized at 600°C. (Table 6). For extrudes carbonized at 700°-750°C. the value was lower.

Iodine absorption values[8] and methylene blue absorption values[9] for the extrudes carbonized at 600°C. are presented in Table 7. These values

TABLE 2—ANALYSES OF EXTRUDES (GREEN AND CARBONIZED)
(on air dried basis)

Particulars of coals used for extrusion	Extrudes carbonized to 600°C. Proximate analysis, %				Calorific value, Btu/lb.	Extrudes carbonized to 700-750°C. Proximate analysis, %			
	Moist.	Ash	V.M.	F.C.		Moist.	Ash	V.M.	F.C.
1. Dishergarh (Chinakuri)	4·1	16·5	8·1	71·3	11,280	5·9 (1·4*)	17·6 (12·7*)	3·9 (28·0*)	72·6 (57·9*)
2. 50% Dishergarh and 50% Jambad-Bowlah	4·9	15·2	8·3	71·6	11,250	1·2 (1·7*)	19·6 (13·5*)	3·6 (21·7*)	75·6 (63·1*)
3. 70% Dishergarh and 30% Jambad-Bowlah	..	..	..	..	..	1·7	20·0	5·6	72·7
4. Poniati (East Baraboni)	4·8	16·8	8·4	70·0	10,980	1·4	15·2	5·9	77·5
5. 90% Poniati and 10% Jambad-Bowlah	5·4	14·6	12·0	68·0	11,250	..	..	..	..
6. 80% Poniati and 20% Jambad-Bowlah	6·0	14·9	8·2	70·9	11,020	..	..	..	..
7. Koithee (Jamuria)	4·0	28·1	7·6	60·3	9,620	2·4	19·9	6·5	71·2
8. Zero seam (Jharia)	..	..	..	..	..	1·1	22·9	3·5	72·5
9. L.T.C. Coke** (Koithee)	3·2	24·7	6·8	65·3	10,210	..	..	..	..

* Values for the corresponding green extrudes.
** Koithee coal carbonized at 600°C. in an electrically heated horizontal retort from room temperature.

TABLE 3—SHATTER TEST OF CARBONIZED EXTRUDES

	EXTRUDES CARBONIZED AT 600°C. Cumulative % on			EXTRUDES CARBONIZED AT 700°-750°C. Cumulative % on		
	1·5 in.	1 in.	0·5 in.	1·5 in.	1 in.	0·5 in.
1. Dishergarh coal (Chinakuri)	57·5	92·5	96·3	..	..	..
2. 50% Dishergarh coal and 50% Jambad-Bowlah coal	nil	73·8	91·3	17·5	87·5	93·8
3. Poniati coal (East Baraboni)	31·3	76·3	92·5	..	..	..
4. Poniati coal 90 % and Jambad-Bowlah coal 10%	11·3	76·3	93·8	..	..	..
5. Poniati coal 80% and Jambad-Bowlah coal 20%	20·0	73·8	93·8	..	..	..
6. Koithee coal (Jamuria)	37·5	83·8	95·0	..	..	..
7. L.T.C. coke* (Koithee coal)	40·0	80·0	93 8	..	..	..
8. Loyabad Coke** (H.T.C.)	..	..	..	65·0	96·3	98·8

* Koithee coal carbonized at 600°C. in an electrically heated horizontal retort.

** Shatter test done according to standard specification (50 lb. of +2 in. coke taken).

TABLE 4—HAVEN STABILITY FACTOR OF CARBONIZED EXTRUDES 700-750°C.

(sample taken, 2·5 lb.)

	SCREEN ANALYSIS Cumulative % on	
	1 in.	0·5 in.
1. Dishergarh coal (Chinakuri)	23·8	43·1
2. 70% Dishergarh coal and 30% Jambad-Bowlah coal	21·0	45·1
3. 50% Dishergarh coal and 50% Jambad-Bowlah coal	24·6	49·8
4. Poniati coal (East Baraboni)	14·1	45·7
5. Koithee coal (Jamuria)	12·0	43·7
6. Sendra coal (XIII and XIV Jharia)	44·4	56·7
7. Zero seam coal (Jharia), Ash 16·0%	26·6	57·0
8. Zero seam coal (Jharia), Ash 17·9%	19·1	51·0
9. Loyabad coke	45·1	55·3

TABLE 5—HAVEN STABILITY FACTOR OF CARBONIZED EXTRUDES 700°-750°C.

(sample taken, 22 lb.)

	Screen analysis Cumulative % on	
	1 in.	0·5 in.
1. 50% Dishergarh coal (Chinakuri) and 50% Jambad-Bowlah coal (Jaipuria Kajora)	22·7	51·7
2. Poniati coal (East Baraboni)	31·8	56·3
3. Loyabad coke* (H.T.C.)	52·3	57·1

* According to standard specification (with 22 lb. of 2-3 in.) % on 1 in. is 52·3.

TABLE 6—CRITICAL AIR BLAST VALUES OF CARBONIZED EXTRUDES 600°C.

	C.A.B. value (cu. ft/min.) at S.T.P.
1. Dishergarh coal (Chinakuri)	0·0106
2. 50% Dishergarh coal and 50% Jambad-Bowlah coal	0·0114*
3. Poniati coal (East Baraboni)	0·0100
4. 90% Poniati coal and 10% Jambad-Bowlah coal	0·0110
5. 80% Poniati coal and 20% Jambad-Bowlah coal	0·0106
6. Koithee coal (Jamuria)	0·0100
7. L.T.C. coke**	0·0106

* C.A.B. value for extrudes of the same mixture carbonized to 700°-750°C. is 0·0100 cu.ft/min.

** Koithee coal carbonized at 600°C. in an electrically heated horizontal retort from room temperature.

TABLE 7—IODINE AND METHYLENE BLUE ABSORPTION VALUE OF CARBONIZED EXTRUDES (600°C.)

	Iodine absorption value (% I absorbed)	Methylene blue absorption value (mg./g. of sample)
1. Dishergarh coal (Chinakuri)	13·26	1·55
2. 50% Dishergarh coal and 50% Jambad-Bowlah coal	13·72	2·85
3. Poniati coal (East Baraboni)	16·61	2·20
4. 90% Poniati coal and 10% Jambad-Bowlah coal	13·72	2·70
5. 80% Poniati coal and 20% Jambad-Bowlah coal	10·29	2·40
6. Koithee coal (Jamuria)	11·85	2·25
7. L.T.C. coke* (Koithee coal)	11·98	2·00
8. Active charcoal	79·31	124·50

* Koithee coal carbonized at 600°C. in an electrically heated horizontal retort from room temperature.

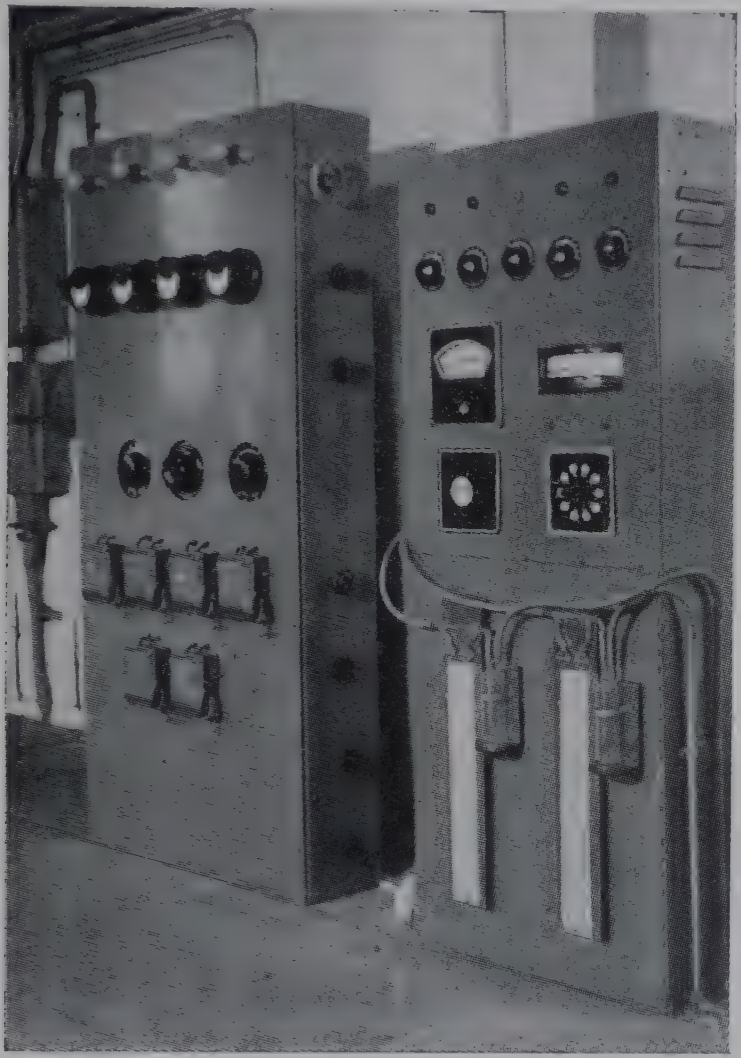

FIG. 3B—CONTROL PANEL

are comparable with those of normal low temperature coke but are much lower than those of active charcoal.

DISCUSSION

The experiments described show that domestic coke as well as metallurgical coke can be obtained from weakly caking coals and noncoking coals blended with weakly caking coals by the process of rapid heating followed by moulding and carbonization to 600°-750°C. A blend of 50% Dishergarh coal (high volatile weakly caking coal) and 50% Jambad-Bowlah (high volatile noncoking coals) gave a coke of metallurgical specification by this process. Similarly a low volatile high rank coal like the zero seam coal also yielded a metallurgical coke.

It has not been possible to vary the pressure of extrusion or measure it exactly, but experiments carried out in the U.S.S.R. in a plunger type dilatometer have indicated the critical nature of the extrusion pressure on the nature and strength of the coke[6]. If the pressure is low or nil, the coke

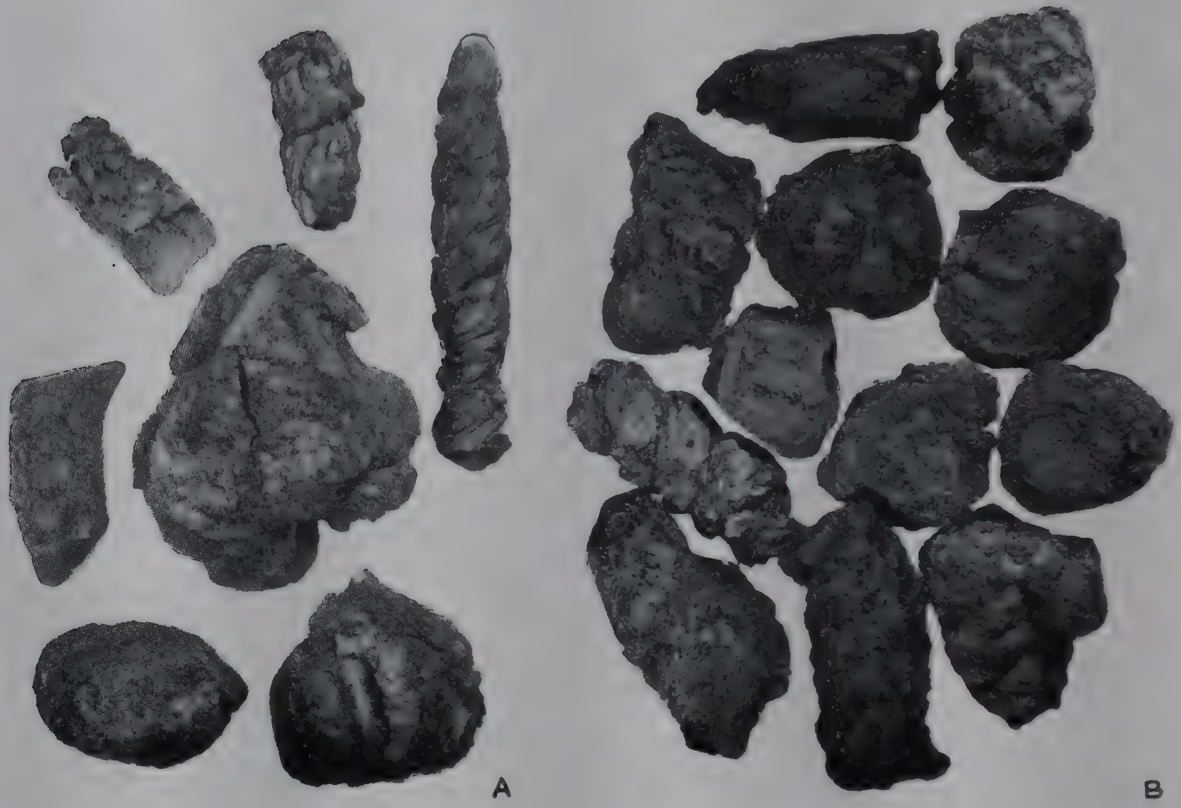

Fig. 4—Extrudes: A—Green; B—Carbonized

will not be good. A pressure of 15-16 atm. is reported to be essential for producing good blast-furnace coke. If the pressure is more than 30 atm. the coking has to be done very slowly to avoid swelling and production of porous coke.

These experiments have indicated that Sapoznikov's process can be adopted to Indian coals, but ways and means will have to be found to increase the production capacity which is one of the limiting factors in this new process.

ACKNOWLEDGEMENT

Thanks are due to the Carbonization Section for offering the facility of determining the C.A.B. value and to the Analytical Section for the analysis of various samples.

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DISCUSSION

Shri S. Sarkar: Dr Iyengar stated in his paper that limitations of this method are that ways and means have to be adopted to increase the production capacity. I had occasion to discuss this with Prof. Sapoznikov in Russia and I have seen his experiments with different capacities. After pilot plant trials, he has been trying to work a plant on commercial scale but due to mechanical trouble the plant could not be worked. So the problem is one of mechanical difficulties; there is jamming in the extrusion channels. The method has no inherent defects.

I would like to know from the authors more about the mechanism of the process and how the coking properties and coking of coal are improved by the process. According to Russian workers both non-caking and gas coals can be used for making metallurgical coke. Is the statement that the caking properties of high-volatile coals are improved by rapid heating true for all types of coals ?

Dr H. Rieschel: In the U.K. the National Coal Board has developed a process for briquetting of non-caking coal. Coal with a volatile matter of 38-45 per cent is devolatilized by carbonizing in a fluidized bed to 20 per cent volatile matter and this char is briquetted in an extrusion press supplied by Buckau. The density of briquettes is larger than 1·2 g./cc. and the quality is also good. This method of treatment has been necessitated by domestic fuel requirements in U.K. where there are no ovens but only open fires.

Dr M. S. Iyengar: The experiments done so far show that the process has good future but there might be certain difficulties when it is tried on a larger scale to increase extrusion capacity. There are two stages in the process. Coal has to be heated to a critical temperature and this can be done on a large scale. The question of extruding it on large-scale in a screw-type of extruder poses a problem. To provide a series of these presses and properly synchronise them present great difficulties. It is not a straightforward process like feeding a coke oven. The extruder that has been tried was designed to extrude 40 lb. of polythene per hour but with coal, only 10 lb. could be extruded. The Russians claim to have put into commission a plant of 400 tons/day capacity but no data are available.

What is it that makes coal caking or non-caking is not clear. It may be that the coking principle is present even in non-caking coal and when coal is heated in the normal way this caking principle may be destroyed. It may not decompose when rapidly heated. Even if coal is rapidly heated strong coke may not be obtained. By rapidly heating, bringing it to the plastic stage and then applying pressure, some sort of chemical reaction or bond takes place and a hard coke may be obtained. Both are necessary to get a hard coke.

The process adopted by the National Coal Board is different. In our experiments coal is heated and a pressure of 15 atm. is applied in a screw press whereas 8-10 tons/sq. cm. pressure is required in an extrusion press. In our process pressure is applied without cooling. I am interested to know whether any binder is employed to obtain coke in the NCB process by fluidized carbonization.

Dr H. Rieschel: No binder is used in this process but the briquetting temperature is about 400°C. and the pressure 1000 atm. Maximum temperature attained by char is 400°C.

The Rexco Process of Low Temperature Carbonization

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An outline is given of the Rexco process of low temperature carbonization by internal heating of the charge with hot gas made by the incomplete combustion of part of the carbonization gas.

Economic and technical considerations of particular interest to countries embarking on a low temperature carbonization programme are particularly stressed.

In low temperature carbonization by external heating the limit set to the thickness of the charge is well recognized, owing to the poor thermal conductivity of the coal. Thus, the weight of coal which can be carbonized in a static retort heated by outside flues is relatively small. To overcome this limitation for static retorts some means of internal heating of the charge must be resorted to.

In the Rexco process, this is done by passing hot gas, derived from the incomplete combustion of part of the carbonization gas, from top to bottom of a large cylindrical retort. The process is one of the few that have survived the test of commercial practice over a period of 26 years; more remarkable is the fact that it has not had to rely on the tar at all for economic success. From the single retort first established at Mansfield, Nottinghamshire, the manufacture has expanded to the present annual output of about 200,000 tons of semicoke from 17 retorts. Active plans are afoot for a considerable further growth, both in Britain and abroad.

The process has been described in detail in two recent publications[1,2]. Thus, only a brief outline of the process will be given here, together with some points of special interest to those contemplating its establishment abroad.

THE PROCESS

Each retort is filled, using a telescopic chute, with 35 tons of graded lump coal. The top of the charge is ignited by some suitable means. The volatile products made are drawn through the retort from top to bottom, and passed to a series of units in a condensation and purification train, in the following order: washbox, tar fog extractor, exhauster and final washer.

In the washbox the gas is scrubbed with cold recirculated liquor, which causes most of the tar to condense and dissolves most of the ammonia. The tar fog extractor is of the cyclone type and condenses the lighter tar and water, centrifugally.

The exhauster from each retort is connected to a common main; through this the combined gas from the battery of retorts flows to another washer in which final removal of tar and ammonia takes place.

Part of the cleaned gas is then returned to the combustion chamber attached to each retort, where it is incompletely burnt with air, and passed into the top of the retort to continue the carbonization. Temperature control is effected by varying the gas/air ratio.

When the carbonization of the top two-thirds has taken place, the cold gas alone is circulated carrying sensible heat from the top to bottom of the retort to complete the carbonization, and cooling the charge to below an average of 100°C. At the end of this cycle (about 17 hr), the partly cooled coke is discharged from the bottom of the retort by withdrawing the hydraulically operated grate. Re-ignition of the semicoke is prevented by spraying with the minimum amount of water.

The coke size is more or less the same as that of the original coal, apart from some degradation. A final screening then takes place.

PRODUCTS

The yields given are per ton of Thoresby coal (high-volatile, weakly caking-bituminous).

Semi-coke: 14·9 cwt per ton

(*a*) For domestic open fires: over 1½ in.
(*b*) 'Nuts', for domestic boilers: 1½ in. to ⅝ in.
(*c*) 'Beans', for commercial heating installations: ⅝ in. to ⅜ in.
(*d*) 'Breeze', for industrial boiler plants: under ⅜ in.

Tar: 18 gal. per ton

Liquor: 15 gal. per ton

This contains about 2·5 per cent of fixed ammonia and is, at present, disposed of entirely as an agricultural fertilizer. It is also a rich source of polyhydric phenols.

Gas: Calorific value, 100-200 Btu/cu.ft.

The gas from any one retort has a variable calorific value depending on the stage of the carbonization cycle. Stepwise operation of the retorts in a battery, however, and the use of the common main, stabilizes this value to a large extent, so that the mixed gas has the calorific value of a cold, clean producer gas.

ADVANTAGES OF THE PROCESS

(*a*) The process is *versatile,* the following materials having been successfully carbonized: weakly and non-caking coals; lignites and briquettes from coals, lignites and peats; and wood, for the production of activated charcoal.

(*b*) Operational advantages are:
  (*i*) Construction is simple and robust. There are no moving parts under heat.
  (*ii*) Process is self-contained as regards heating gas.
  (*iii*) Throughput is large.
  (*iv*) Charging is quick ($\frac{3}{4}$ hr)
  (*v*) Start-up is quick (15 to 20 min. from the cold).
  (*vi*) Any retort can be shut down after discharge.

(*c*) Labour for operation need be only semi-skilled and unskilled.
(*d*) Output per unit area of land is big, because of large retort capacity.
(*e*) Capital cost of construction is low.
(*f*) Maintenance and operating costs are low.
(*g*) Rate of depreciation is low and life of plant is long.
(*h*) Disposal of liquor is no problem where it can be used as a fertilizer.

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DISCUSSION

Dr S. K. Sircar: In the Rexco process, internal heating takes place by gasifying part of the charge. The retort appears to be of a producer type which was tried in U.K. some 40 years ago. Is Rexco process a development of this producer ?

Dr M. Vahrman: The Rexco retort is actually a development of one used in the processing of oil shale in the U.S.A. It certainly resembles a gas producer, in that it is a large cylinder and that hot gaseous products pass through it. But it does not operate mainly by gasifying the charge, but as has been mentioned in the paper, by part of the gas made in carbonization being incompletely burnt in a separate chamber, and the products then being passed through the coal charge to continue the carbonization. Steam-carbon reactions do occur, however, to a minor extent.

Shri D. P. Agrawal: Since in the Rexco process, a part of coal is heated more in the beginning, the quality of coke may not be uniform and the tar may not be true l.t. tar.

Dr M. Vahrman: The tar from the Rexco process can be classified as a true low temperature tar (see my later paper in Section III, which includes a tentative classification of such tars).

The variation in temperature in any individual retort is between about 700°C. at the top and 550-600°C. at the bottom, although the temperature in the combustion chamber is above this. The importance of temperature is obvious, but the importance of residence time is sometimes not taken sufficiently into account. It is possible, for example, to get a true l.t. tar in a process where the actual temperature of carbonization is high, but the tar is taken out quickly, thereby not allowing time for much cracking of it to occur in hot zones.

Further, different series of tar components are affected to varying degrees. Hydrocarbons found in l.t. tars, part of which have been shown to be present as such in the original coal, are less affected by cracking than the complex bitumens which yield phenols on decomposition. It is interesting to note that down-jet tar, although passing through zones in the furnace at above 1000°C. is still a l.t. tar because of the extremely short residence time.

Dr M. G. Krishna: It seems to me that the coke from different zones of Rexco retort may not be of the same quality. In this connection, I refer to the paper of M. Meurisse where the coke briquettes from middle and bottom have almost same volatile matter while those from the top have different characteristics probably due to excessive heating or ignition of the charge at the top of the retort.

Dr M. Vahrman: The ignition system is so located that the hot gaseous products enter at the top of the retort. Thus, especially in the initial stages of carbonization, the temperatures at the top are necessarily higher. But the coke from a battery of retorts is of a fairly uniform quality, as the gas, being taken from retorts in various stages of a carbonization cycle, tends to even out in composition, and as sufficient time is given for completing the carbonization in accordance with a laid-down schedule of operations. In fact, the coke quality is more even than in most processes where external heating of retorts is used.

In the work described by M. Meurisse, the briquettes were carbonized by conducting "cage" tests, the procedure used when information is wanted on the behaviour of a fuel in a full-scale Rexco carbonization, but when sufficient quantity is not available to fill a single retort. Here, the lignite briquettes were packed into a metal cage which was suspended in a normal commercial Rexco retort, surrounded by coal of the usual quality used. Carbonization conditions were not ideal, accounting for some variation in quality. It would evidently be a better procedure, if the tonnages were available, to pack one or preferably several retorts with these briquettes and to carbonize under normal conditions. Nevertheless, the tests yielded products of good quality and showed that Rexco retorts were suitable for this sort of carbonization.

Shri H. C. Chakrabarti: I am interested in the heat requirements for carbonization of coal in the Rexco process. The variation, in the calorific value of gas given as 100-200 Btu/cu.ft is rather high. The variation normally expected is 100-150 Btu/cu.ft. How is the surplus gas used ?

Dr M. Vahrman: The variation in calorific value of gas from a *single* retort can be still higher—of the order of 100 to 500 Btu/cu.ft—in accordance with the different stages in the carbonization cycle of the coal: all carbonization processes have this in common, and a levelling out of quality is achieved by mixing of gases. When a battery of several retorts is operated, therefore, the calorific value varies, as I have mentioned before, between much narrower limits. The surplus gas, of producer quality, is used for steam-raising in boilers, and the steam or gas can also be used for other processes in the works, for example, for the recovery and treatment of byproducts. It could, of course, be used for other purposes, e.g. feeding it into a gas grid, after enrichment.

Dr M. S. Iyengar: What is the proportion of fines expected by carbonizing a high volatile, weakly caking, bituminous coal in the Rexco plant ? How does the tar yield in the actual plant compare with the yield from Gray-King assay ?

Dr M. Vahrman: The size of coke obtained roughly corresponds to the size of coal fed into the retort. With a coal of 1-5 in. size range, there is produced some undersized coke up to about 20 per cent.

The actual yield of tar from the Rexco plant using the normal weakly caking coal (N.C.B. classification No. 801) is 19 gal./ton (9·5 per cent) as compared with 9·9 per cent for the Gray-King assay.

Production of Smokeless Briquettes by Semi-carbonization

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An account of the experimental study to prepare a smokeless briquette of low ash and sufficient strength from the surplus washed coal fines is given. Semibituminous coal from Ressaix and gas coal from Winterslag were briquetted using pitch as binder after addition of sulphur and carbonized in a Rexco retort on small scale. The results suggest that an industrial-scale plant would be justified.

At a conference organized at Liege on June 20, 1960, the Institut National de l'Industrie Charbonniere brought out the importance of briquetting in the upgrading of coal and the necessity of making the briquettes smokeless in order to ensure that they are commercially competitive.

Normally washed fines find a market either as coking slack or for blending with other coals. Thermal power stations are generally equipped to use middlings, of which there is a large surplus at the present time. Industrial heating uses a small part of the surplus washed fines, particularly in the pulverized form. It is difficult to make use of washed fines in domestic heating without having special equipment, e.g. continuous screw feeders, air ducts, etc. In the latter fields there is considerable competition from oil products.

The coal producer, finding it difficult to sell all his washed fines, looks for a method of upgrading the fines to a commercially marketable form, directly applicable to meet domestic requirements.

The 20-30 mm. anthracite is one of the preferred domestic coals used for heating, because it is sufficiently hard, dustless, easily handled and smokeless. Moreover, it maintains a good fire and, if sufficiently washed, leaves very little ash during combustion. For this reason anthracite is capable of competing with petroleum products as a domestic fuel.

The problem is then to manufacture from washed fines a fuel comparable with or superior to 20-30 mm. low-ash anthracite. To do this, the first step is to produce washed fines of very low ash content. Modern technical processes can produce coals of 3 to 4 per cent ash and when the object is to make products for domestic use, it would be a good commercial practice to produce such coals. In fact, one of the principal reasons for the public dislike of solid fuels is the ash content which is often too high. The average consumer, on seeing this quantity of inert material, often gets the impression that he is paying dearly for a product which is only partly combustible and consequently requires constant attention and cleaning of the fire.

Starting with low-ash washed fines two operations are possible: (*i*) low temperature carbonization, and (*ii*) briquetting.

When the coal possesses all the required qualities to give a good semicoke, the first solution is certainly very attractive.

Whereas high temperature coke is difficult to burn and has a relatively high ignition temperature, the semicoke is a very reactive smokeless fuel, particularly well adapted to domestic fire places. It has a very low density which may offer certain disadvantages. Also all coals unfortunately do not possess the necessary agglutinating properties. Slow carbonization at low or medium temperature leaves only a powdery product of no commercial value. This applies particularly to low-volatile coals. For washed coal fines, therefore, briquetting is essential either before or after thermal treatment. The briquetting of coal after thermal treatment is not yet found possible on an industrial scale. The studies of CERCHAR have shown the superiority of the briquette over a graded product of similar ash content with regard to its burning qualities; the former, owing to its uniform ash distribution, holds together better in the fire than the graded fuels, in which the ash is irregularly distributed. Moreover, briquettes unlike natural solid fuels, offer the advantage of supplying a product of uniform quality. Unfortunately, briquetting requires a binder. Coal-tar pitch is the most commonly used binder though it is highly smoke producing.

Coal briquettes are unpopular mainly due to the considerable amount of smoke and soot produced on combustion and also their ash content. It is generally admitted that the use of briquettes causes the sticky deposits in chimneys and boilers. The remedy lies in placing at the disposal of the consumer a smokeless briquettes of low ash content with a good appearance and of correct size and enough strength to prevent excessive breakage during transport. Moreover, if this product can be sold at a competitive price, the surplus washed fines can be upgraded as has been proved in the markets of different countries.

The present communication gives an account of the experimental study made on this problem. In a pilot plant a small vertical oven was used which gave satisfactory results. During the period of semi-industrial tests, the Rexco retort was successfully utilized, but it is possible that other ovens could eventually prove suitable.

The semibituminous coal from Ressaix and the gas coal from Winterslag have been tested using the patented process for improvement of pitch-bound briquettes by the addition of sulphur, which was tried on a pilot scale. Table 1 gives the analyses of these coals.

GENERAL DESCRIPTION OF THE REXCO PROCESS

The oven consists of a cylindrical vertical steel retort, lined with refractory of 3·30 m. diam. and 7·30 m. height with a capacity of 34 tons. The bottom of the retort is moveable and consists of an inclined grate supporting the coal and permitting discharge of the product by gravity.

Charging of the oven is from the top by means of a telescopic chute thus reducing breakage and size segregation. Heat is transferred to the mass by passing burnt reducing gas at 780°C. obtained by the incomplete combustion of part of the produced purified gas in a precombustion chamber. The test installation is not always equipped thus, the generation of hot gas taking place in the dome of the retort itself. In the latter case, the lighting of each charge is effected from the top of the retort by means of added fuel (wood and gas oil). Carbonization progresses from the top downwards and once two-thirds of the charge is carbonized, heating is stopped by shutting off the air and gas alone is recycled. This absorbs the sensible heat of the carbonized mass to complete the carbonization of the charge and simultaneously ensure cooling of the product.

The average carbonization temperature is 700°C. the maximum temperatures at the top and bottom being 730 and 650°C. respectively.

The coking rate is controlled through the gas temperature at the bottom of the retort (Fig. 1).

The coking time is 14 hr of which 8 hr are required for effective heating and 6 hr for heat transfer and cooling. In addition, maintenance and charging take 2 to 3 hr.

PREPARATION OF THE BRIQUETTES

The briquettes were prepared from a very fine crushed mixture consisting of 94 per cent coal and 6 per cent pitch of 70° (K & S), 2 per cent sulphur being added in the case of the Ressaix coal and 2·5 per cent in the case of Winterslag coal. Finally 0·5 per cent anthracene oil was added in both cases during mixing.

The briquetting was carried out at the experimental station of INICHAR, efforts being made to keep as close as possible to industrial marketing conditions and to conform to the composition of the mixture

TABLE 1—ANALYSES OF COALS

	WINTERSLAG	RESSAIX
Moisture, %	3·4	2·4
Ash, %	4·7	7·2
Volatile matter, %	23·4	14·4
Sulphur, %	0·85	0·83
Dilatometric test (Arnu)		
Start, °C.	375	460
Max. contraction, %	—30	—14 Contraction only
Max. dilatation, %	+125·0	..
Swelling index	9·0	1·5
Gieseler plastometer test (35 g.)		
Start, °C.	370	..
Plasticity zone, °C.	63	..
Max. fluidity	4,000	
Solidification, °C.	490	..
Size of analysis of mixture (94% coal +6% pitch) after crushing		
Oversize at 500 μ, %	2·6	2·4
500—246 μ, %	8·8	8·0
246—104 μ, %	30	25·8
104— 44 μ, %	42·2	43·0
<44 μ, %	16·4	20·8
Briquetting conditions Constitution of the mixture		
Coal	94·0	94·0
Pitch	6·0	6·0
Anthracene oil	0·5	0·5
Sulphur	2·5	2·0
	103·0	102·5
Temp. of the mixture, °C.	78-80	81·5
Moisture in the mixture, %	2·8-3·5	1·6-2·3

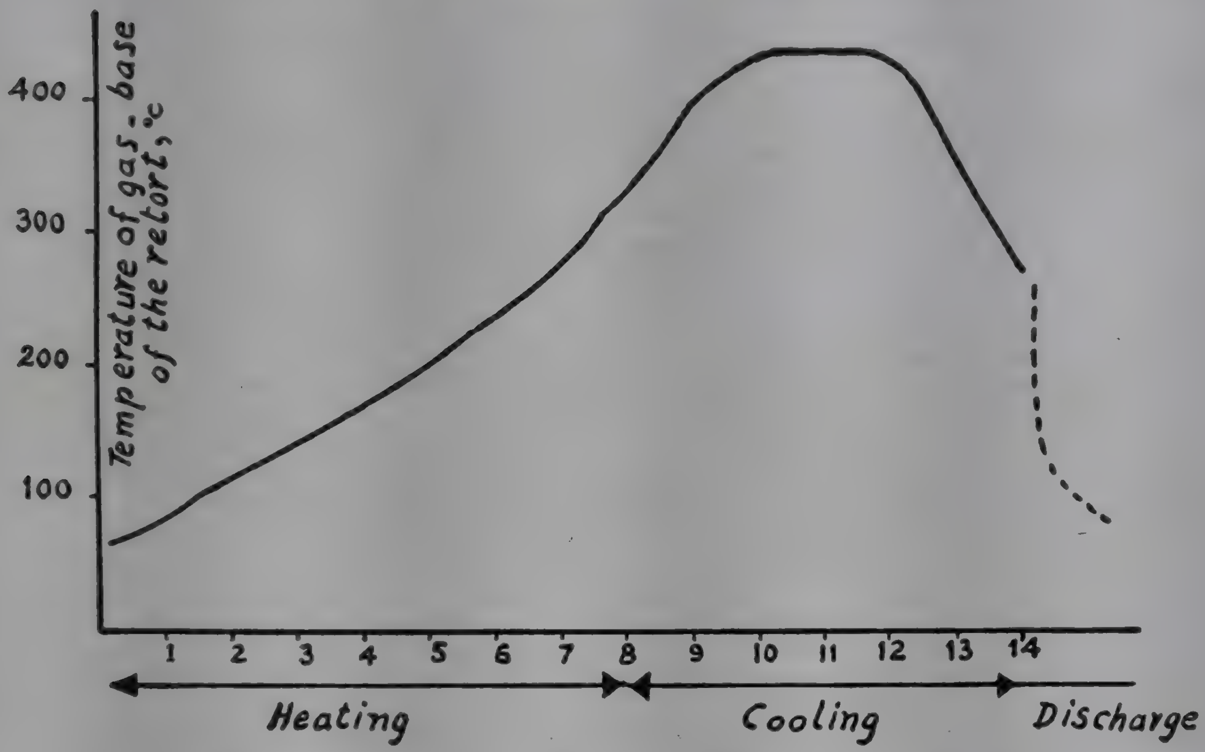

Fig. 1—Carbonization cycle of briquettes in Rexco retort

studied in the laboratory, particularly in respect of the minimum binder to be used.

Briquetting was carried out after heating the mixture at 100°C. by superheated steam at 250°C., adding 4 per cent of water, and final intense mixing for 10 min. (Lodige type of pug-mill).

The briquettes, so produced have a good appearance. Fig. 2, however, reveals the so-called "duckbill" defect which was impossible to avoid because of a fault in the press.

SEMI-CARBONIZATION TESTS IN THE REXCO RETORT

Three latticed baskets of 20 mm. mesh, each containing about 7 kg. of briquettes were placed in the retort and covered manually by 40 cm. of large coal in order to avoid the introduction of coal into the basket during charging; the first basket was placed at 1·5 m. from the grate, the second in the middle of the charge and the third at 1·5 m. below the top of the charge. The charge of coal consists of 34 tons of high volatile gas coal of 50 to 125 mm. size and 11 per cent moisture.

Coking was conducted normally in 14 hr but cooling was prolonged by 4 hr in order to avoid the degradation of samples by ignition at the moment of discharge from the retort.

RESULTS ON BRIQUETTING OF WINTERSLAG COAL

General. During the thermal treatment the briquettes underwent

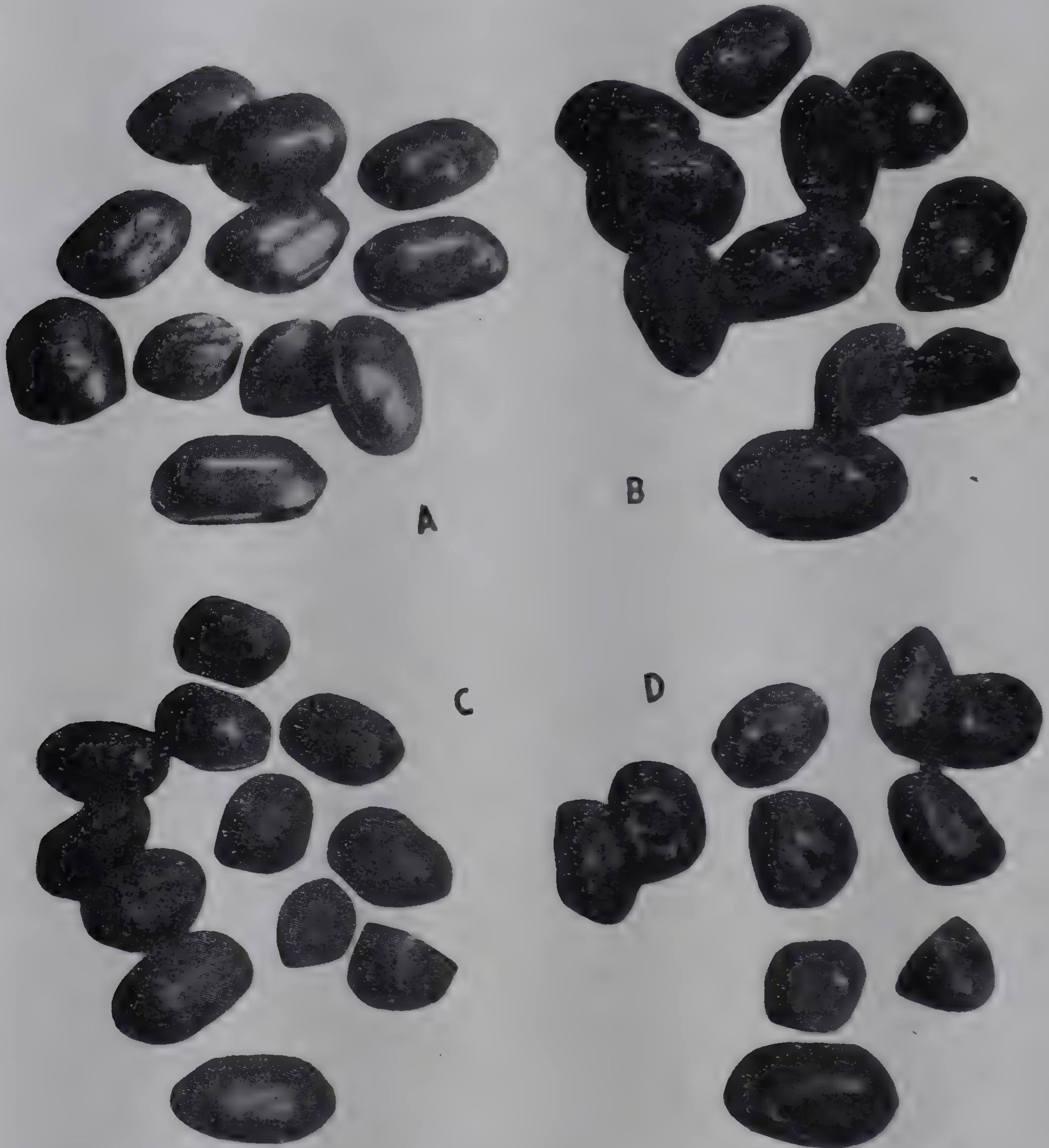

Fig. 2—Raw and carbonized briquettes: A—Briquettes from the Press, B—Briquettes before charging, C—Briquettes after semi-carbonization (Ressaix coal), D—Briquettes after semi-carbonization (Winterslag coal)

some degree of fusion leading to deformation from the effect of the load and, in some cases, sticking together in bunches.

In Fig. 2D can be seen the indentations made by one briquette upon another and also the imprint of the wire mesh of the container made while the briquettes were in the plastic state. This result, though not perfect, should, however, be regarded as remarkable, considering that the briquettes were made from one of the best Belgian coking coals.

Figs. 2A, 2B and 2D show: (*a*) The degradation resulting from the handling of the green briquettes (2A and 2B), the light degree of fusion accompanied by a minimum of swelling has, however, given a grey metallic shine to the surface of the briquettes, (*b*) the homogeneous and porous texture of the briquettes, (*c*) absence of dust from the carbonized briquettes, and (*d*) the obvious fusion of certain briquettes as well as traces of a fragile sintering.

TABLE 2—GENERAL PROPERTIES OF WINTERSLAG AND RESSAIX COALS

	WINTERSLAG				RESSAIX			
	Green	Top	Middle	Bottom	Green	Top	Middle	Bottom
Proximate Analysis.								
Ash, %	4·0	5·7	5·4	5·5	6·8	7·8	7·9	7·7
Volatile matter, %	26·8	2·5	5·7	5·2	18·2	5·4	5·7	5·5
Total sulphur, %	2·96	..	..	0·92	2·62	0·93	0·94	0·83
Gross calorific value, kcal./kg.	8,219	..	..	7,473	8,015	..	..	7,422
Physical Analysis								
Weight of a briquette, g.	20·8	14·9	15·8	16·4	20·6	16·6	18·0	18·1
Volume of a briquette, ml.	19·08	16·72	15·83	15·89	18·72	13·71	14·63	14·95
Variation of volume by carbonization, %	..	12·36	17·03	16·71	..	..	—21·80	—20·10
Sp. gr.	1·090	0·891	0·998	1·032	1·100	1·211	1·230	1·210
Absolute density	1·293	..	..	1·783	1·363	..	..	1·622

(*Contd.*)

TABLE 2—*Contd.*

	WINTERSLAG				RESSAIX			
	Green	Top	Middle	Bottom	Green	Top	Middle	Bottom
Porosity, %: calculated	15·7	..	..	42·12	19·30	..	..	25·40
measured	15·1	..	..	40·96	18·45	..	..	21·38
Crushing resistance, kg.	51·7	139·0	200	>200	36·6	97·8	166	168
Test in muffle at 950°C. appearance of smoke	Immediately	None	None	None	Immediately	None	None	None
Deformation	Large	Slight scaling	None	None	Large	None	None	None
Per cent yield calculated on:								
Loss of weight	..	71·63	75·96	78·85	..	..	87·38	87·86
Loss in volatile matter	..	73·15	77·67	77·51	..	..	86·66	86·49
Heat Balance (thermal efficiency)								
78·85×7473/8,219	..	..	..	71·69	..	..	..	..
87·86×7422/8,015	..	..	..	..	..	..	..	81·36

In principle such a product could satisfy the domestic market, and also be suitable for industrial purposes.

The object of these tests was not, however, to upgrade in this way the Winterslag coal for which a more judicious use in the production of metallurgical coke is already assured, but only to prove that when briquettes from strongly caking coal can be carbonized at low temperatures under specific conditions it is possible to subject briquettes from inferior coals to the same treatment. The chances of success are found to increase with a decrease in the coking characteristics of the coals.

Quality of Briquettes

Composition. The analysis of green and carbonized briquettes shows an increase in the ash and a decrease in the volatile matter and the calorific value as is usually the case. The analytical results are given in Table 2.

The volatile matter content of the briquettes placed in the middle and at the bottom of the retort is almost identical, while, the briquettes placed at the top have different chemical and physical characteristics resulting from the particular ignition system used where combustible material is fed into the top of the charge, which involves, at the start, a slightly oxidizing atmosphere. This does not occur in a normal battery with separate combustion chambers and a common gas circuit.

The added sulphur has been completely eliminated from the briquettes, and the remaining sulphur corresponds to that introduced with the coal. Tests in the laboratory have shown that by indirect heating, the sulphur is removed in the form of hydrogen sulphide. The technical problem of its evolution still remains in the Rexco process.

Physical Properties. The modifications in the physical properties of the briquettes affected by low temperature carbonization have a bearing on the high resistance to crushing (greater than 200 kg.) despite the deformations caused during the operations by the application of force to weak points of the briquettes, the increased porosity which increases and the decreased specific gravity which decreases of the briquettes. The value of these two are very close to that of metallurgical coke. The carbonized briquettes introduced in a muffle furnace, heated at 950°C. burn with a light blue flame and without any smoke and remain coherent after 20 min. in the furnace, while the green briquettes swell and emit immediately large quantities of soot. However, the briquettes placed at the top of the charge "scale" slightly.

Yield. The yield has been calculated both from the loss of weight and from the diminution of volatile matter content of the briquettes on carbonization. The results in both instances are very close. As stated before, the briquettes placed in the upper part of the retort result in having different properties. The yield calculated from the loss in weight shows clearly that there has been a real combustion, traces of which are not visible upon the briquettes due to the fusion which imparts a smooth and a relatively bright surface to all the briquettes. The thermal balance envisaged from the ratio between the initial and final calorific values of the solid fuel in question, i.e. 71·69 per cent corresponds very closely to that recorded in coking plants. Surplus calories can be disposed off to ensure carbonization.

RESULTS FOR THE RESSAIX COAL BRIQUETTES

General. The samples did not undergo any deformation during treatment, as is evident from Fig. 2C, showing briquettes from the bottom or in the middle of the oven. Figs. 2A, 2B and 2C show: (*a*) the degradation resulting from handling of the briquettes, (*b*) the bright surfaces which are noticeable after carbonization, (*c*) the reduction in size of the carbonized briquettes by nearly 20 per cent without any deformation (no breakage, cracks or swellings), and (*d*) the compact and homogeneous texture of the briquettes.

Consequently, from a marketing point of view a product of impeccable appearance can be produced.

The briquettes placed at the top have kept their shape but are less coherent and are eroded nearly to a depth of 2 mm. This fault results from the particular lighting up system used as explained earlier.

The resistance of these briquettes to crushing is nevertheless high owing to an unoxidized core of hard and compact texture.

Quality of Briquettes

Composition. The analysis of the green and carbonized briquettes reveals the usual changes in ash content, volatile matter content, and the calorific value. It was found that: (*a*) The volatile matter content of the carbonized briquettes was particularly constant even at different levels, and (*b*) the added sulphur was completely eliminated from the briquettes.

Physical Properties. Semi-carbonization causes important modifications in the physical properties of the briquettes. In particular the relatively low crushing strength of green briquettes increases considerably on carbonization degree attaining values higher than those expected in commercial practice. The reduction in volume being greater than the loss of weight, causes an appreciable increase of specific gravity, approaching that of anthracitic coal. This, combined with the regularity of shape and hardness of the material, constitutes a favourable commercial factor, especially from the "customer's storage" point of view. The carbonized briquettes introduced into a muffle furnace, heated to 950°C. burn with a light blue flame without any smoke and preserve their cohesion after 20 min. in the oven, while the green briquettes swell and emit immediately great quantities of soot.

Yield. The yield was calculated both from shrinkage and loss of weight as explained earlier. As shown in Table 2 the values obtained by both methods are very close but slightly greater than the 85 per cent yield predicted by theory.

Taking into account a certain degree of unavoidable breakage in industrial operation, this yield of 85 per cent is confirmed. As shown in Table 2 the anticipated thermal balance of 81·36 per cent is relatively high. From an exploitation point of view, only an industrial test can show whether the residual 18·64 per cent can supply the necessary heat for carbonization.

Recent Developments in Briquetting and Low Temperature Carbonization of Weakly Caking Coals

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Recent developments in briquetting and carbonization of weakly caking coals for the production of smokeless fuels are reviewed. Hot briquetting, autogenous carbonization on travelling grates and fluidized carbonization are described. The likely yields of various products by carbonizing 20 million tons of coal per year are indicated.

It has been estimated by the National Council of Applied Economic Research (N.C.A.E.R.) that cattle dung and wood equivalent to 100 million tons of coal per year are being used as household fuel in India. This quantity of dung burnt per year can produce, if used as a manure, about 9 million tons of food grains per year, equivalent in value to the production of twelve Sindri factories.

The present urban demand equivalent to about 20 million tons of coal per year is met mainly from coal, electricity, kerosene, firewood and dung. In rural areas the demand is equivalent to about 77 million tons of coal per year of which nearly a half is met from dung and the other half by wood. The N.C.A.E.R. has recommended that the supply of domestic fuel in rural areas, being essentially a local problem, should be tackled at the rural base. They have suggested the supply of soft coke from low temperature carbonization (l.t.c.) of coal starting first with big cities and extending it to larger areas in the next decade. For the current household consumption of the big cities in India, nearly 3 million tons of coal equivalent is required. The N.C.A.E.R. has recommended starting of eight plants in big cities, each of capacity 1000 tons per day, with an aggregate capacity of 2·5 million tons per year. This production will finally be increased to 50 million tons in 1980, involving a capital outlay of Rs. 500-600 crores.

SMOKELESS FUEL

One of the most important methods of producing a smokeless fuel consists in briquetting of the low-grade coals and subsequent carbonization. But a simple process comprising these two treatments is applicable to only a very limited variety of coals. To develop a suitable process for utilizing a wider range of coals it would be necessary to carry out experiments with indigenous raw materials.

The essential properties of a domestic fuel for use on open grates are: (1) high reactivity, so that the fuel may be easily ignited, (2) uniform size and resistance to breakage, and (3) low ash content. The process and plant employed mainly depend upon the type of coals available. Coking coals are generally carbonized in a finely divided state, and weakly caking and non-caking coals in lumps. In some processes completely noncoking coals are ground well and briquetted before carbonization, with or without a binder. Briquettes can also be made from coking coals by suitably pretreatment, i.e. oxidation prior to briquetting. Low volatile but highly swelling coals are usually oxidized before briquetting in order to control the subsequent carbonization behaviour of the briquettes.

BRIQUETTING AND CARBONIZATION

Some of the important factors that govern the quality of the carbonized briquettes obtained from bituminous coals are the carbonization conditions, the briquetting technique used, the binder employed, and the physical characteristics of the material briquetted.

In the studies carried out in recent years in various countries, it was revealed that the process of briquetting remains, to a very large extent, uninvestigated. To carry out extensive studies on the briquetting of bituminous coals an experimental set-up shown in Fig. 1 has been advocated by the German Association of Coal Technology. The installation is to be equipped with most modern machines including several types of presses, crushers, and equipment for screening, drying and mixing. The capacity, under commercial conditions, may be up to 15 tons of briquettes per hour, the weight of individual briquettes being 20, 50 or 1000 g. A special pitch which is a mixture of normal pitch and tar oils together with a certain

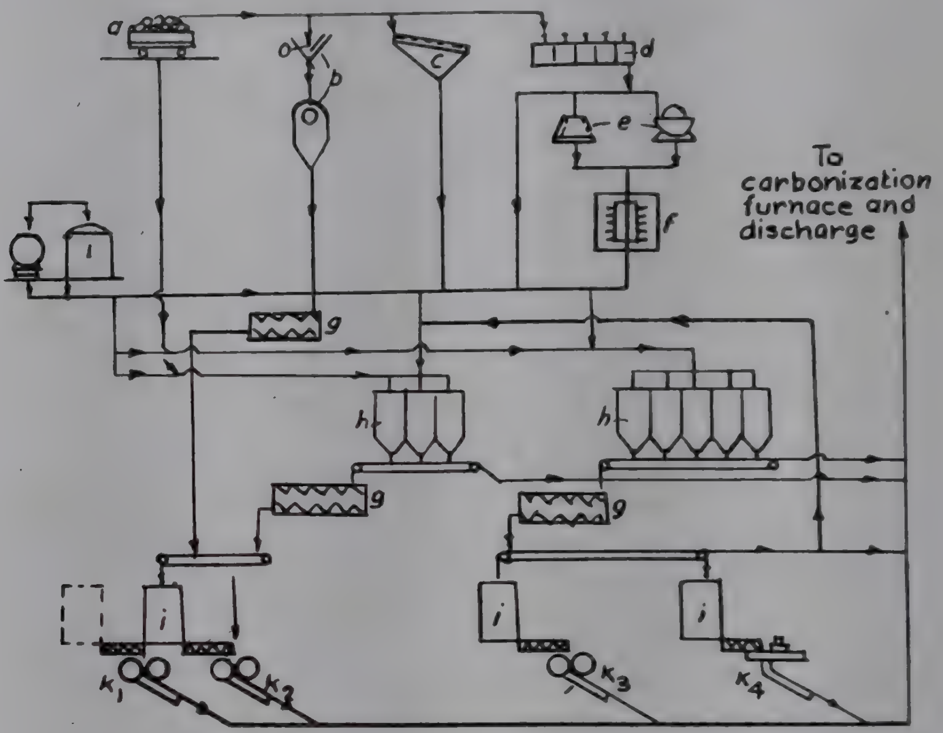
a
b
c
d
e
f
g
h
i
k1
k2
k3
k4
l
To carbonization furnace and discharge

FIG. 1—EXPERIMENTAL PLANT FOR TRIALS OF BRIQUETTING AND CARBONIZATION: (a) Test coal (b) Crusher (c) Screening plant (d) Floatation (e) Dewatering (f) Drier (g) Mixer (h) Storage (i) Pug mill (k_1) 20 g. press (5 tons/hr) (k_2) 50 g. press (5 tons/hr) (k_3) 20 g. press (15 tons/hr) (k_4) 1 kg. press (7 tons/hr) (l) Heating vessel for liquid binder

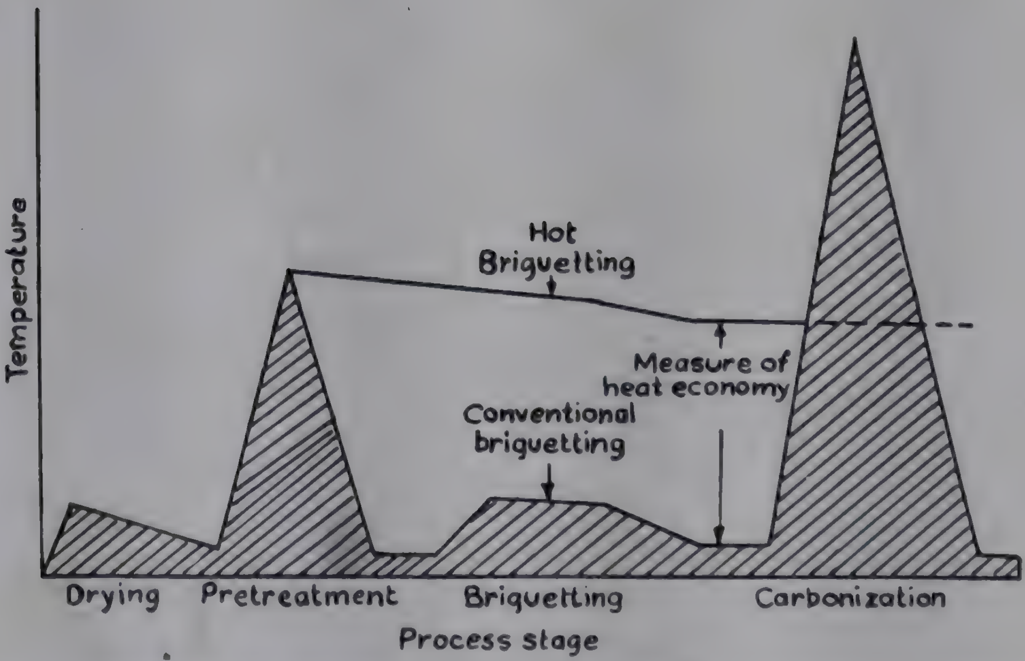

FIG. 2—PROCESS TEMPERATURE LEVELS FOR CONVENTIONAL AND HOT BRIQUETTING

amount of crystallized aromatic compounds has been developed for use in briquetting. One of the principal advantages of this material is that it eliminates the need for drying the material to be briquetted. The binder is injected in a fluid state at a temperature of 145-150°C. into the coal to be briquetted. The quantity of binder necessary is not more than 5·3 to 5·4 per cent. The National Coal Board, England, are interested in using low softening point binders. They have preferred to use topped tar (softening point 40-45°C.) obtained from the distillation of a crude tar at a temperature of approximately 300°C. as the binder. Emulsified petroleum bitumen binders have been found by them to be particularly suitable for briquetting wet coal even at atmospheric temperatures.

HOT BRIQUETTING

A process using pretreatment of coal illustrated by Gregory[1] is shown in Fig. 2. He suggested that to improve the overall thermal efficiency of such a process it is necessary to briquette at or near the temperature of the pretreatment stage. In the conventional briquetting process using coal tar pitch as binder, coal after pretreatment is cooled to about 80°C. and then briquetted. The briquettes are then cooled to near ambient temperatures to permit the pitch to set and impart sufficient strength to the briquettes for transportation to the carbonization plant. The briquettes have to be again heated and cooled after coking. Thus instead of repeated heating and cooling, if hot briquetting can be done it will result in heat economy. But the briquettes manufactured at the pretreatment temperature should be sufficiently strong at that temperature for mechanical handling. The usual binders are effective only after they harden and, therefore, new binder with high setting temperatures has to be employed. Previous workers[2] have shown that fine coals could be agglomerated without a binder to form briquettes if the coal is first heated so that it becomes plastic and then compressed. But many of the coals decompose before softening and the evolution of gases hinders the compression necessary for briquetting. The National Coal Board has developed a fluxing agent (e.g. coaltar pitch) which makes the coal fusible over a wider temperature range, as shown in Fig. 3. By this means the range of coals which soften before decomposition is widened and the permissible briquetting temperature is increased. Kardaun[3] in his experiments on hot briquetting found that as the volatile matter of the coal goes beyond 12 per cent, serious difficulties are encountered, such as deformation, cracking and clustering of the briquettes. Preliminary oxidation or degasification is therefore necessary. Some work[4] has also been successfully done by using coal of low fusion characteristics as a binder. It has been found that as regards hardness and abrasion resistance, the uncarbonized briquettes are of the same quality as good pitch-bound briquettes.

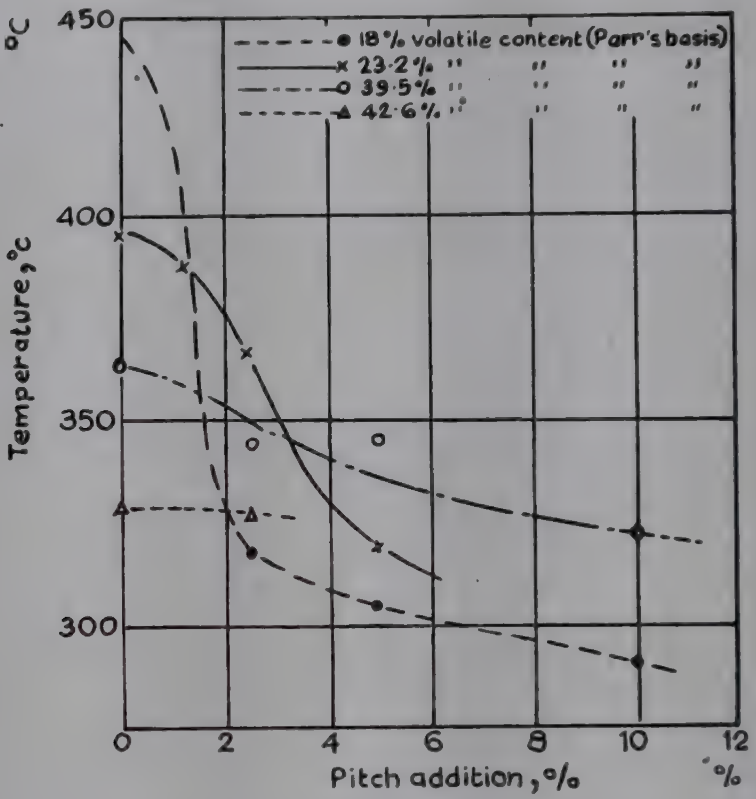

Fig. 3—Effect of pitch addition on softening temperature of pitch and coal mixture

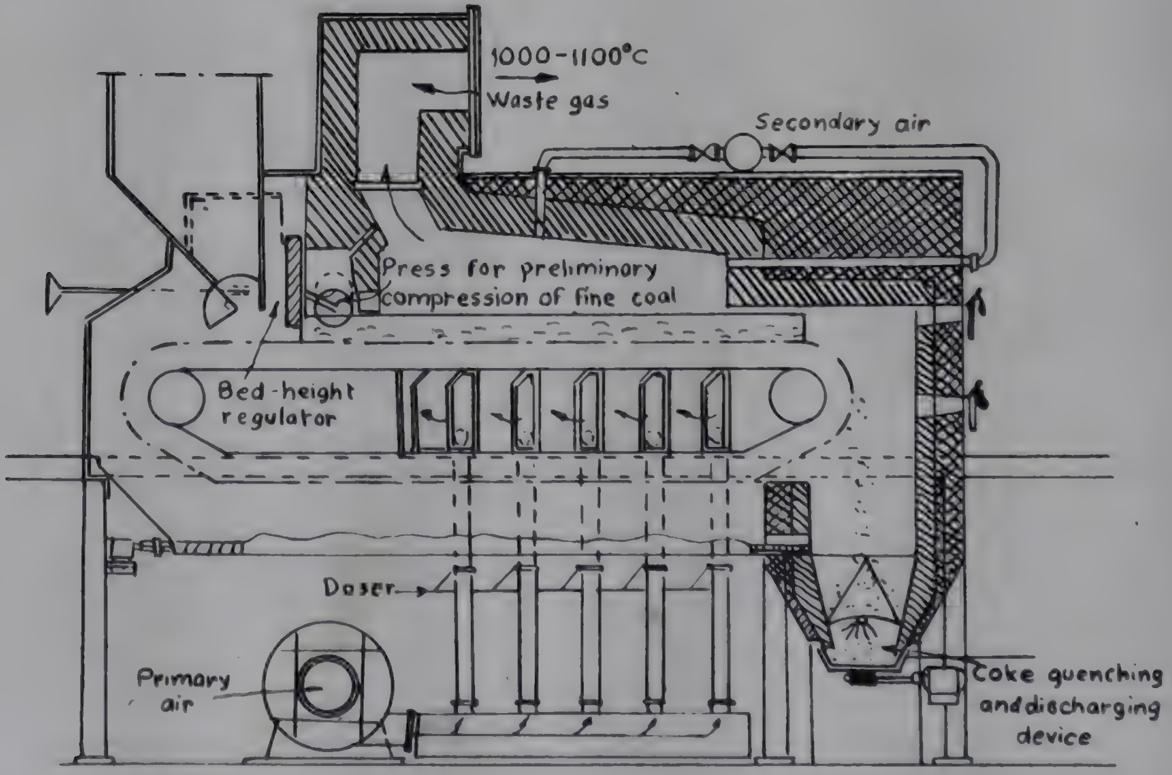
1000-1100°C
Waste gas
Secondary air
Press for preliminary compression of fine coal
Bed-height regulator
Doser
Primary air
Coke quenching and discharging device

Fig. 4—Travelling-grate grid carbonizer for autogenous carbonization of hard coal and lignite briquettes

AUTOGENOUS CARBONIZATION ON TRAVELLING GRATES

In India, where the principal interest is in the production of smokeless fuel, coals of low and medium volatile content or semicoke fines should form a large part of the raw materials required. These are to be briquetted with pitch and/or coking coal. The first step is to obtain a good briquette which will meet the requirement of the normal physical standards. Subsequently, the briquettes will have to be carbonized. This conversion will increase the hardness or resistance to abrasion. The ingredients used for the briquetting, and their behaviour during coking, are most important. Carbonizability is greatly affected by variations in coking temperature and heating rate. The smokeless fuel must have some residual volatile matter left to make it easily ignitable. Consequently, it is not necessary to use high temperatures as in ordinary coking. According to Kurt Baum[5] the briquettes should be carbonized for not more than 20 to 100 min. depending on the nature of the raw materials used. The short heating times can be attained either by direct heat transfer from hot gases or preheated solids or in certain cases by the so-called autogenous coking.

Large-scale attempts have been made in U.S.A., Canada, Germany and South Africa to carbonize coal and briquettes on travelling grates. It has been claimed that this system modifies the fixed carbon content as little as possible and make briquettes which are capable of withstanding storage and transport. A sketch of the travelling grate carbonizing plant is given in Fig. 4. An air-cooled grate which is sealed along its long side against a water cooled wall moves in a furnace of refractory material. By means of suitable devices the rate of movement of the grate and height of the bed on the grate can be adjusted. The rate of movement of grate can be varied between 44 and 340 mm./min. The height of fuel bed can be adjusted between 0 and 220 mm. The effective heating area is 4·45 sq. in. Air can be blown in controlled quantities through the grate from a series of air chambers. The gases leave the furnace in a flue above the coal inlet. The coke is discharged at the end of the grate on to a water cooled shaker trough, which guides the carbonized material through a water spray to the storage. Underneath the grate a discharge device is provided to remove from the furnace any material which may fall through the bars. The advantage of such a carbonizer is that it can be heated up in four hours by simply burning off the volatiles from the starting up fuel. Once the brickwork has reached a temperature of 1000°C., carbonization may be started and stopped at any time. To obtain a lower temperature, it is necessary to supply the primary air with a higher content of nitrogen. This process of autogenous carbonization can be utilized for production of smokeless fuel from briquettes. The hot reaction gases can be recycled through the incoming charge to effect heat exchange.

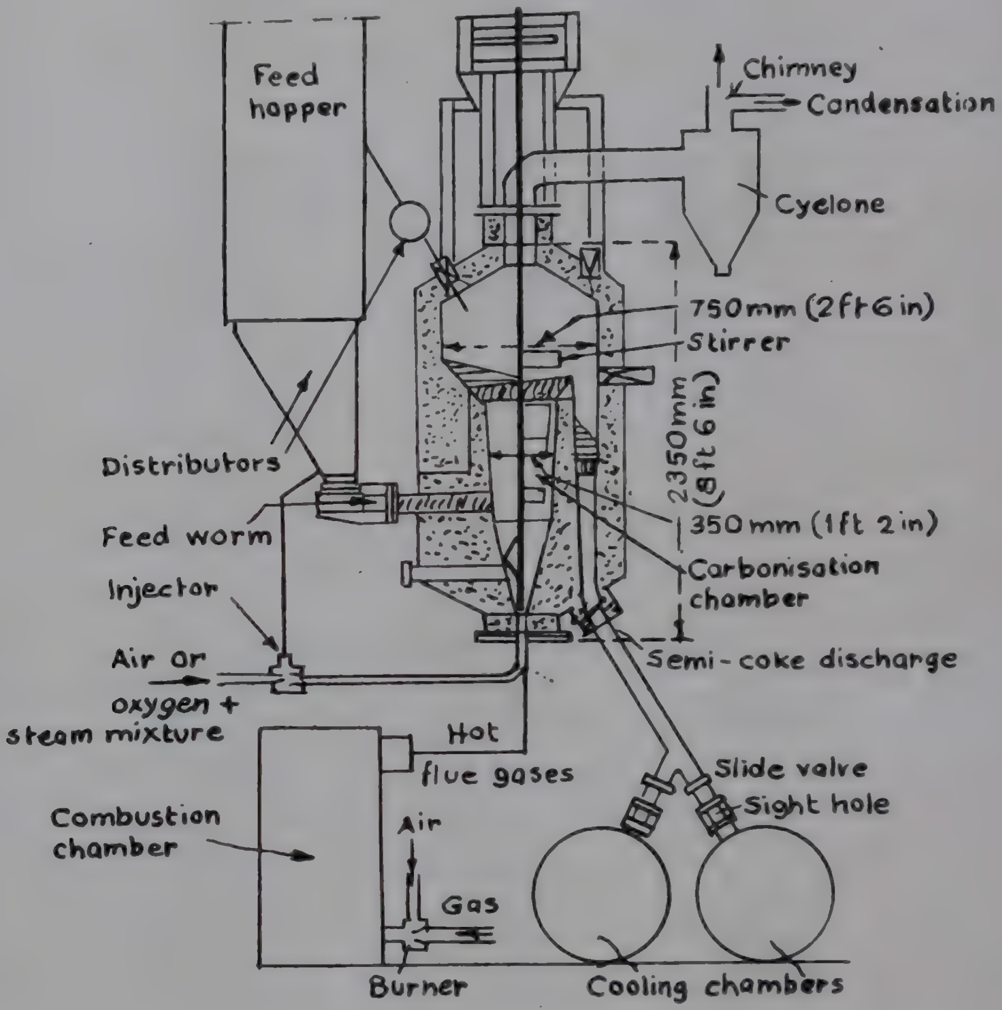
Feed hopper
Chimney
Condensation
Cyclone
750mm (2ft6in)
Stirrer
2350mm (8ft 6in)
Distributors
Feed worm
350mm (1ft 2in)
Carbonisation chamber
Injector
Air or oxygen + steam mixture
Semi-coke discharge
Hot flue gases
Slide valve
Sight hole
Combustion chamber
Air
Gas
Burner
Cooling chambers

FIG. 5—FLUIDIZED CARBONIZATION PLANT

SEMI-CARBONIZATION IN A FLUIDIZED BED

Carbonization of coal at low or medium temperature yields three principal products: semicoke, tar, and gas. The objectives can be different according to the emphasis laid on one or the other of these products. Peytavy and Foch[5] outlined the interesting work being done at CERCHAR and Marienau, France, on the recent techniques for the production of semicoke. They are applying the fluidization technique to coal carbonization and are studying the behaviour of coal, the quality of the products obtained and material and thermal balances. Various methods were considered and a method making use of internal heating by partial combustion of the coal in the draught air has been preferred. When the plant is, in addition, provided with a suitable preheater to preheat the coal and air, the throughout can be increased, and the quality of the gas improved. A sketch of the experimental fluidized carbonization plant of 1/4 ton/hr capacity is shown in Fig. 5. This unit was put into operation in 1954. The furnace proper is made up of two parts: (a) The carbonization chamber consisting of a cone surmounted by a truncated cone, where, in principle, the fluidization occurs. A grid can be set between the cone and the truncated cone; (b) The storage bunker, situated above the carbonization chamber. As this is considerably larger than the carbonization chamber, there is sufficient room for an annular space which allows the semicoke to overflow. The draught consisting of air, a mixture of oxygen and steam or of hot flue gases is blown into the lower part of the carbonization chamber. The fuel is fed in different ways: (a) by a feed worm, (b) by dropping it from the top of the apparatus, and (c) by an injector through which the draught is blown. The semicoke is discharged from the carbonizing chamber by overflow into the cooling vessels. The gas is freed from dust in a cyclone and passed through a condenser. A rotary stirrer is placed inside the furnace. The semicoke obtained is a fused mass and is relatively friable. The difference in the semicoke obtained by this process and by other carbonization processes is that the appearance and structure of the semicoke depend not on the temperature reached, but on the rate of heating. The semicoke produced by fluidization is of a very uniform quality under clearly defined conditions of operation. Similar work has been carried out by the National Coal Board, England, mainly on the measurements of total heat required for carbonizing low rank coals with very interesting results.

C.F.R.I. PLANT

This consists of two continuous type narrow vertical firebrick retorts, made on similar lines to the one originally developed at the Fuel Research Station, Greenwich. This is a versatile plant and besides production of smokeless fuel, it may also be used as a gas plant or for production of coke for low-shaft furnaces, carbide industry, etc. The ground area covered is 12,000 sq. ft.

If 20 million tons of coal per year are processed to smokeless fuel by l.t.c. to meet the urban demands in India, it will yield 15 million tons of soft coke, 1·6 million tons of tar oils and 3 million cu. ft of rich gas. Tar will yield 160,000 tons of valuable phenolic chemicals. In addition, 2-3 per cent of tar bases are available for other chemicals and pharmaceuticals. The remaining 1·4 million tons of tar oil can be hydrogenated to 1·1 million tons of diesel oil which can replace about 10 million tons of high-grade lump coal, which is about 50 per cent of the railway's requirement in the Third Plan. The gas can replace another 6-8 million tons of coal for domestic and industrial uses. The capital outlay will be approximately Rs 150 crores for coal processing and Rs 150 crores for tar processing. The chemicals obtained will be valued at Rs 25-30 crores per year.

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Carbonization of Solid Fuels at Low and Medium Temperatures

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The general ideas contained in the report (ST/ECE/Coal/3) published by the working group in 1960 are described. An account is given of the general lines of development of carbonization (low and medium temperatures) industry, especially in Europe, during the periods, prior and subsequent to the Second World War. The various technical and economic considerations involved in the process are discussed and the need for the exchange of information on an international level is emphasized.

Carbonization of coals at low and medium temperatures has been studied for many decades both from technological as well as economics point of view. The working group on use of coals published a report (ST/ECE/COAL/3) in 1960 and the general ideas contained in it are presented here.

Developments in coal carbonization have been most noticeable in countries which have large deposits of lignite and coal. However, if during the period between the two World Wars, industry based on low and medium temperature carbonization had not developed in relation to its importance, it was because, all the resources, both technical and financial, were spent on increasing the production of iron and rationalizing the coke industry. The attention of carbonization plants was focussed, mainly on the manufacture of metallurgical coke from high-quality coking coals of which these countries gave the impression of having an ample supply and little was known of the results achieved in some countries on the process of coal carbonization at low and medium temperatures.

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Since the last war, the importance of carbonization at low and medium temperatures has been appreciated, because of the possibility of fuller utilization of the lignites and coals, and also because of the changes that have taken place in the fuel resources. Some regions of Europe found themselves totally lacking in coking coal or their resources of coking coal greatly reduced. Some other regions found it difficult to obtain supplies of petroleum products. In many cases, this resulted in completely new industrial installations, adopting a new method of utilization of the available solid fuel resources. The United States also participated in this effort. This paper attempts to describe this new method which is still in full evolution and whose economic importance has not yet been sufficiently proved.

OBJECTIVES OF THE METHOD

Semicoke, primary tar, ammoniacal liquor and gas are the basic products of the operation. Semicoke alone represents 60 to 80 per cent by weight of the coal treated. This massive proportion of the semicoke in the products is also evident in the economics governing the process. This principle can be enunciated as: Living by the coke, deriving the benefit from the byproducts. This principle can be more explicitly stated by the relationship:

$$a + f + g \leqslant kv$$

where:

a = purchase price of one tonne of raw coal supplied to the factory
f = manufacturing costs of treating one tonne of raw coal
g = general charges per tonne of coal treated
k = ratio by weight of commercial semicoke obtained for one tonne of the coal treated
v = average selling price per tonne of semicoke, ex-factory.

Therefore, the first anxiety of the enterpreneur has been and is to make the production of semicoke paying.

The need to avoid pollution of the atmosphere and in many cases, the short supply of lean coals (low volatile) have led to studies with a view to obtain semicoke in the form of easily ignitable, abrasion-resistant, small pieces. The fuel should not crumble on ignition and possess a radiant power at least equal to the fuel habitually being used.

Owing to the reactivity of semicoke in the form of small pieces, it can be advantageously used in gas producers producing good yield of gas and facilitating ease of operation. The semicoke can thus become a basic raw material for the manufacture of synthesis gas.

It is especially well-suited for low shaft furnaces, for the manufacture of ferro-silicon and calcium carbide, as a reducing agent in the metallurgy of zinc and tin, and also as an agglomerating agent for iron-bearing minerals in roasting.

Lastly, semicoke is also used in rotatory furnaces or in pulverizing hearths especially when it is obtained in powdery form.

But, it is especially as a thinning agent, i.e. a component of coke pastes, that the semicoke has been more frequently used since the last war.

Production of Semicoke as a Domestic or Industrial Fuel. The use of semicoke as domestic or industrial fuel makes the atmosphere in large cities more hygienic. It is the partially burnt constituents of the tar, liberated during combustion of coal which pollute the air. Semicoke is practically free from these tars.

Development of the production of semicoke in small pieces took time because of certain technical difficulties and also because of lack of enthusiasm on the part of the consumers towards this new fuel, both due to its cost as also the scepticism about the advantages of the new fuel.

As the fifth general report on the activity of the Communauté Europèeune du Charbon et de l'Aciev (European coal and steel Common Pave) has emphasized, a continued scarcity of lean and anthracite coals is to be expected as their resources will go on diminishing. It is therefore necessary to develop substitute fuels especially by improving the agglomeration and carbonization at low temperature.

These developments not only induced the semicoke producers to continue with their production, but also to improve their installations and create newer ones, since new markets had to be opened up, particularly for the small sized semicoke which could not otherwise be used in the homes.

Use of Semicoke as a Thinning Agent in Coke Pastes. The possibility of using semicoke as a thinning agent in coke pastes was realized even before the last war and the scarcity of caking type of coal in many areas, opened up a new market for semicoke. Fat coals (high volatile) suitable for production of semicoke being available in larger quantities have come to fill in an indirect way, the gap left by the growing scarcity of lean coals and thus help to increase the supply of coal. Before being added to the coke paste, semicoke should be carefully pulverized.

Studies carried out on the optimum particle size of semicoke to be used in coke pastes show that the M_{10} of the resultant coke is less satisfactory, the greater the size of the semicoke elements and the higher the percentage of the semicoke employed beyond a certain optimum value. Thus, of the three particle sizes, 0·2 mm., 1 mm., 3 mm., the one with 95 per cent less than 1 mm. is the most advantageous, because, on adding 5 per cent semicoke the M_{40} increases from 69·8 to 70·8 and this increases to 71·3, when 10 per cent of semicoke is added with a slight deterioration of M_{10} which changes from 6·9 to 7·5.

Semicoke obtained in a powdery state, particularly from installations employing fluidization technique, appears to be quite suited for this purpose. It should, however, be noted that when this semicoke is to be used in place of coke dust as a constituent of the coke paste, it should be treated at 800°C. and as in the case of coke dust, its particles should be very fine. Under these conditions, the antifissure properties of the semicoke are very close to those of the coke dust. The most favourable particle size is less than 0·5 mm., which, admixed with 7 per cent powdered coke, gives M_{40} of 79·0 and M_{10} of 7·5 for the coke obtained. This result is almost identical to what one would have obtained on addition of 7 per cent coke dust; a suitable grinding of the constituents of the coke paste will only improve these results.

In all these applications, the powdered semicoke obtained by fluidization will be more useful than the pulverized semicoke obtained from revolving furnaces.

Chemicals from Products of Carbonization. Till now emphasis was laid on the solid product alone, but markets are growing for the liquid and gaseous products, particularly in the chemical industry. Increase in their use in the manufacture of plastic materials and artificial textiles among others, illustrate the possible developments. This appears to be even more important from the qualitative aspect and the returns it gives than from the quantities involved.

During the period 1920-40, countries like U.K. and Germany lacking in petroleum found themselves in a delicate position regarding the supply of petrol. To meet this situation, production of synthetic petrol from lignite and coal by distillation at low or medium temperature and hydrogenation of the liquid products was thought of. Starting from lignite, which is particularly suitable for this kind of treatment, an extremely important coal chemical industry was developed in Germany and even coals were used for the manufacture of liquid hydrocarbons.

For this purpose the lower the temperature at which the carbonization is done the lighter is the tar obtained, and more favourable is the production of aliphatics and naphthenes compared to the aromatics. Results have shown that tars of low specific gravities cannot profitably be obtained at temperatures higher than 500°-550°C.

Low temperature (l.t.) tar (amounting to 10-12 per cent in yield) can be considered as a light hydrocarbon characterized in general by high content of phenols (sometimes up to 40 per cent). Thus for coals from Ruhr, it was found that the larger their tar content the higher was their yield of phenols. Fat coals were found to yield tar with 15-20 per cent phenols, gas coals, 25 to 35 per cent and long-flame gas coals, 35 to 55 per cent. This property appears to be related to the oxygen content as is indicated by the behaviour of cannel coals of low oxygen content, which give a poor yield of phenols (24 per cent at the most) and which contain a large amount of solid paraffins (18 per cent as against 1 to 1·5 per cent for other coals) which makes the extraction of their tar acids difficult.

Due to complex composition of the l.t. tars their chemistry was not as much developed as in the case of high temperature tars. L. t. tars differ from high temperature tars in their high phenolic content (even up to 20 times more), by the absence of crystallizable polynuclear hydrocarbons and by their relatively low pitch content. The particular difficulties encountered while dealing with l.t. tar are due to the higher thermal sensitivity and greater reactivity, making it necessary to use stainless steel at the required places. This explains why, till a few years after the last war, these tars were used chiefly for hydrogenation, or sometimes even simply as liquid fuels.

However, further studies on the treatment of these tars and the experience gained since the last war on the refining of petrol has thrown more light on the nature of these products. It has been possible to obtain from these tars, firstly oils with a high (40 per cent) phenol content, used in the manufacture of disinfectants or creosote, heavy liquid fuels, and also pitch. On further processing, these tars give tar acids which form the basis of insecticides and fungicides, and crude phenols, which, after rectification give carbolic acid (90 per cent), *o*-cresol (80 per cent), *m*-, and *p*-cresol (45 per cent) and pitch.

All these substances can also be obtained in an almost pure state by a more complete rectification. The phenolic substances constitute a basic raw material. While carbolic acid can also be made by synthetic methods, cresols and xylols have no other source except the coal tar. Carbolic acid (90 per cent) is of great value in the manufacture of phenol-plastic moulding powder. *O*-cresol is used in the manufacture of various products used in agriculture such as insecticides and fungicides, and *m*-, and *p*-cresols form the base for varnishes and gums (electrical insulators) as well as of stratified plastics. Cresylic acids not only find use in the manufacture of phenol-plastic resins but are also used as flotation agents as well as desulfurizing agents in the petroleum industry.

RAW MATERIALS TREATED

After the First World War the question soon arose on making proper use of non-caking coals, which, on suitable treatment could yield valuable liquid and gaseous products in addition to a solid residue of good calorific value. Though these coals could be used as fuels, such use was wasteful since valuable byproducts were lost and at the same time thermal efficiency was poor.

These considerations in the first instance led to a precise evaluation of coking coals. Next, with the progress made in mixing techniques, the category of coals likely to yield coke, alone or on mixing, was enlarged. There were, however, some types of coal which could not be added to coking coals, but which on account of their tar yield were specially suitable for carbonization at low or medium temperature. From studies carried out it became apparent that coals with more than 30 per cent volatile matter were particularly interesting from this point of view, and the coals with 16-17 per cent volatile matter, to a lesser extent.

Lignites proved to be the best raw material for the purpose because of their yield of tar and gas and also their water content which made them a poor fuel in the raw state. Moreover, the lignite deposits are easily exploitable, often by open-cast mining making it available at an extremely low cost.

This explains the development of lignite industry in Germany during 1920-40. During this period Germany achieved an annual production of 2 million tons of primary tars by treatment of 35 million tons of crude lignite. The tar was subjected to hydrogenation. The choice of temperature of lignite carbonization was solely dictated by the quality and yield of liquid products, they being the economic backbone of the process. The semicoke obtained was then considered as a byproduct. From the tar, solid paraffins, diesel oil, fuel oil, electrode-cokes were made along with production of synthetic petrol by refining. During the last war, the primary tar became an essential raw material for the production of petrol by hydrogenation, while the semicoke was mostly used in the gas-producers for the production of synthesis gas. However, later as a result of the increased supplies of petroleum and considerable improvement in refining capacity, the utilization of the lignite tars for production of petrol practically lost its importance and treatment of primary tars was oriented towards the production of other valuable products.

The treatment of coals on the other hand, did not progress similar to lignite. The attention during this period was mostly concentrated on high temperature carbonization. For other fuels like peat, the usefulness of this treatment is slowly beginning to be realized.

TECHNIQUES EMPLOYED IN THE VARIOUS METHODS OF CARBONIZATION

The choice of the process, differs from one country to another, because apart from the nature of the fuel treated, the objectives aimed at depend upon several factors both economic and political.

However, two well-defined tendencies were noticeable with regard to the principal aim of the operation: (i) production of semicoke for domestic and industrial needs, (ii) production of primary tar and gas to be fed to chemical industry.

Considerable experience was gained in the construction of furnaces which has resulted in the development of furnaces with improved conditions of carbonization, both from the thermal as well as economic considerations.

At present, the furnaces can be classified in general into three types: (i) static furnaces, (ii) rotating furnaces, and (iii) furnaces involving fluidization technique.

Static Furnaces

The firms, Lurgi and Krupp, even before the last War, developed a process of carbonization of coal in static bed in a metallic chamber heated externally to 500°-600°C. At that time, an installation of this type, was erected at Wanne-Eickel in the Ruhr, with an annual capacity of 132,000 tonnes of coal. This installation worked in combination with a synthetic petrol plant producing about 50,000 tonnes per year of primary products. The reactive semicoke was used in the gas-producers for production of synthesis gas.

Another installation was erected at Velsen in the Saar with an annual capacity of 66,000 tonnes of coal for the production of semicoke for household use (small heaters, central heating, Baker's furnace, etc.). This installation has been greatly modified after the war, with a view to produce semicoke intended for use as thinning agent in the coke paste.

During the last few years, modifications have been introduced in the preliminary treatment of coals, for example, predrying of coals with addition of coke dust. This has had a very good effect on the quality of semicoke and the economics of the process. Predried washed fines of 0-10 mm. size (36 per cent volatile matter, 8 per cent moisture, 7 per cent ash and a swelling index of 6·75) were used, which gave a semicoke with 12 per cent volatile matter, 2·5 per cent moisture, 10·5 per cent ash and showing an M_{40} of 60 to 62.

In another plant in Saar, 0-10 mm. dry flame coal fines with 39 per cent volatile matter, 9 per cent moisture, 7·5 to 8 per cent ash with the following particle sizes were used after pulverizing or other preliminary treatment: 0 to 1 mm.—19 per cent; 1 to 2 mm.—23 per cent; 2 to 4 mm.—25 per cent; 4 to 6 mm.—19 per cent; 6 mm. and above—14 per cent. These fines gave an yield of about 77 per cent (on dry basis) semicoke with 12 per cent volatile matter, 10·3 per cent moisture, 9·8 per cent ash; at the same time 110 cu. m. of gas with a lower calorific value of 6,059 kcal./cu. m. was produced per tonne of coal carbonized.

The semicoke obtained in the Lurgi furnace with Saar coals was perfectly satisfactory as thinning agent for coke paste if carefully pulverized before being introduced into the paste.

Rotating Furnaces

Among rotary furnaces, the Koppers furnaces give from fat coals with more than 35 per cent of volatile matter, a semicoke in pieces which can be used as such for domestic fuel or after pulverizing as thinning agent in the mixture intended for coke making.

If the semicoke produced in Koppers furnaces is compared with that from the Lurgi-Krupp furnaces, at first sight it appears that Lurgi-Krupp process is preferable but other factors will have to be taken into consideration before making a final choice, particularly the nature of the constituents of the coking paste to which the semicoke is to be added and the pulverization process to which this will have to be previously submitted. The influence of these two factors has not been thoroughly studied and it would be very useful if more clarity is brought in this field on the basis of the experience acquired in the operation of rotary furnaces. The production of this semicoke as a domestic fuel has made considerable advance, as is shown by the manufacture of Carbolux. For many years a smokeless domestic fuel called 'coalite' is produced in U.K. in metal-walled static furnaces.

Fluidization

This technique derives its inspiration from catalytic cracking of petroleum oil and the term 'Fluidization' is applied in this case to layers of solid particles supported by a rising current of gas (or liquid) whose thrust balances the weight of the particles.

This extreme mobility of the particles has many advantages, of which the following are industrially more important: (i) it considerably increases the heat transfer coefficients in the fluidized bed resulting in an increased capacity of the reactors; (ii) it makes it possible to bring about with exceptionally favourable yields the complex chemical reactions taking place during the operation, because of the very intimate contact between the solid particles and the fluidizing medium; and (iii) it facilitates the handling of the fluidized mass which behaves like a liquid.

The fluidized carbonization first applied in the United States is in fact applicable to all fluidizable fuels, particularly to lignite and coals and is capable of opening markets to those fuels that cannot be utilized easily in the raw state. On this process, which is still in a semi-commercial state of development, opinions can be formed even now, based upon the experience acquired in the United States and France.

Coals from Saar and Loraine treated by this method give a semicoke formed of fine smelted elements. The volatile matter diminishes rapidly with increase in temperature and a complete distillation is obtained without having to raise the temperature beyond 700°-800°C. Further, this semicoke has antifissure properties very similar to those of the coke dust.

It was possible to solve the problems encountered in the early days of application of this method, and particularly dust removal from the gas, condensation of tar, cooling of the coke and even to find technical solutions for preheating and achieving proper thermal balance and general improvement of the installation.

By preheating coals up to the threshold of pyrogenation (300°C.) with or without preheating of the air (500°C.) it has become possible to: (i) increase the yield of semicoke with diminution in the yield of ash, (ii) improve the quality of gas which contains less inert constituents, and, (iii) decrease the volume of the fluidizing medium, which cuts down the size of the condensing system.

On the basis of the views (assessed from people of different countries) and especially those from Eastern countries, it is felt that the future of this method of treatment of coal rests, principally on processes based on fluidization, although processes based on this technique have not yet been perfected and still present many problems.

Studies carried out in Loraine have indicated the possibility of establishing two types of installations for carbonization. In one case the accent would be on the use of the byproducts, and in the other on carbonization with autothermal cracking with production of only the semicoke and the gas.

There is scope for much progress, particularly in the case of processes involving two or more stages. These processes presuppose a preliminary agglomeration and a subsequent distillation resulting in increased use of those coals which are difficult or not at all amenable to distillation in the raw state. This is also a very difficult problem because of the number of stages involved, but the results obtained so far have been encouraging.

ECONOMIC AND ENERGY ASPECTS OF THE OPERATION

It has often been said that the problem of better utilization of solid fuels, notably coals is above all an economic and financial problem involving enormous investments, which might become remunerative only if the state starts, runs or subsidizes such industries. This question is still controversial.

The literature on the economic and energy aspects of the operation is not adequate and the comparison of scanty information available on the production costs and investment is difficult because of the differences that exist from one country to another. It is obvious that the comparison would be easier if these figures were established on a common basis, for example as a function of the hours of work and the quantities of materials used.

The Coking of Non-caking Coals and the Production of Briquette Coke

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The experimental coke-oven plant of 10-18 tonnes per day at the Research Institute for Heavy Chemical Industries, Budapest is described. This plant is suitable for the carbonization of lignites, brown coals and high volatile bituminous coals. Data about the gas and tar yields and the heat requirements for carbonization are given. Tar yields of 80-100 per cent on Fischer assay yields have been obtained. The coke obtained from bituminous coal is suitable for domestic purposes. Briquettes of lignite and brown coal crumble during carbonization. When these are briquetted with caking coal and pitch, the briquettes can be carbonized in a continuous vertical retort according to the stepwise charging technique. The smokeless carbonized briquettes with 3 per cent of volatile matter can find use in domestic heating appliances and central heating boilers.

The substantial part of Hungary's coal reserves consists of brown coals and lignites with a moisture content of 30-50 per cent, in addition to brown coals of higher rank, with a moisture content of 12-16 per cent. The reserves of caking coal are limited. Research activity was, therefore, centred primarily on brown coals. Since 1920 several industrial plants to utilize coal have been set up and research activity in the field considerably developed.

The Institute endeavoured to develop industrial processes, favourable from the technical as well as the economics point of view, for low and high temperature carbonization of brown coals, and for production of lump coke– briquette coke—from brown coals. On the basis of data, collected on laboratory, pilot-plant and industrial-scale tests, it has been concluded that the following aspects have to be taken into consideration in the carbonization of non-caking coals and brown coals:

1. The heat consumption for the drying and preheating of coal forms a substantial portion of the total heat requirement. Brown coals disintegrate during drying and are susceptible to spontaneous combustion.

2. The drying and the carbonization process, though spatially separated, should be carried out in à sequence, each by the most appropriate method.

3. The volatile content of the coke should be reduced about 2 per cent by carbonizing at about 900°C. as coke of higher volatile content is liable to spontaneous combustion and is also difficult to store and transport.

4. Carbonization gas has to be obtained in undiluted state, if it is intended to be used as basic component of town gas.

5. The coke from brown coal cannot be quenched with water, but has to be cooled with carrier gas and before being discharged from the oven.

6. To improve the heat economy, the heat has to be recovered from the glowing coke and reused in carbonization.

7. Coke from brown coal, being of small size and crumbling nature, has a low marketability. The coke has to be briquetted admixed with pitch and moderate quantities of caking coal. On carbonizing these briquettes, smokeless briquette coke can be obtained.

8. Gas from carbonization of brown coal has a very high organic sulphur content (150 to 500 g./100 Nm^3), which has to be removed and decomposed separately.

Keeping all these considerations in view a pilot plant with an oven of 10-18 tons per day capacity was constructed at the Institute for carbonizing non-caking coals. The plant consists of two parts: a carrier gas dryer and a coking oven situated below. The cross-section of the plant is shown in Fig. 1.

The dryer is similar to Lurgi's carrier gas dryer. Its shaft has an internal cross-section of 1.34 × 1.85 m. and an internal height of about 4.5 m. Carrier gas, produced in the combustion chamber at about 250°C., is introduced below the bottom saddles, the substantial part of this gas is exhausted by a fan at a point below the middle saddles and recirculated through the combustion chamber. Excess gas and steam are vented through a stack connected to the uppermost series of saddles. The volume of circulated gas varies between 1200 and 3200 Nm^3/hr, depending on the quality of coal and experimental conditions. The moisture content of the dried coal varies between 0 and 10 per cent, its temperature between 90° and 110°C.

The dryer is separated from the oven by two Z-locks (Fig. 1, No. 3), by turning them with a ratchet, the coal is conveyed through the connecting chutes (Fig. 1, No. 4) into the oven.

The oven consists of three parts: the predistillation chamber forming the top part, the carbonizing chamber, surrounded by heated walls, placed

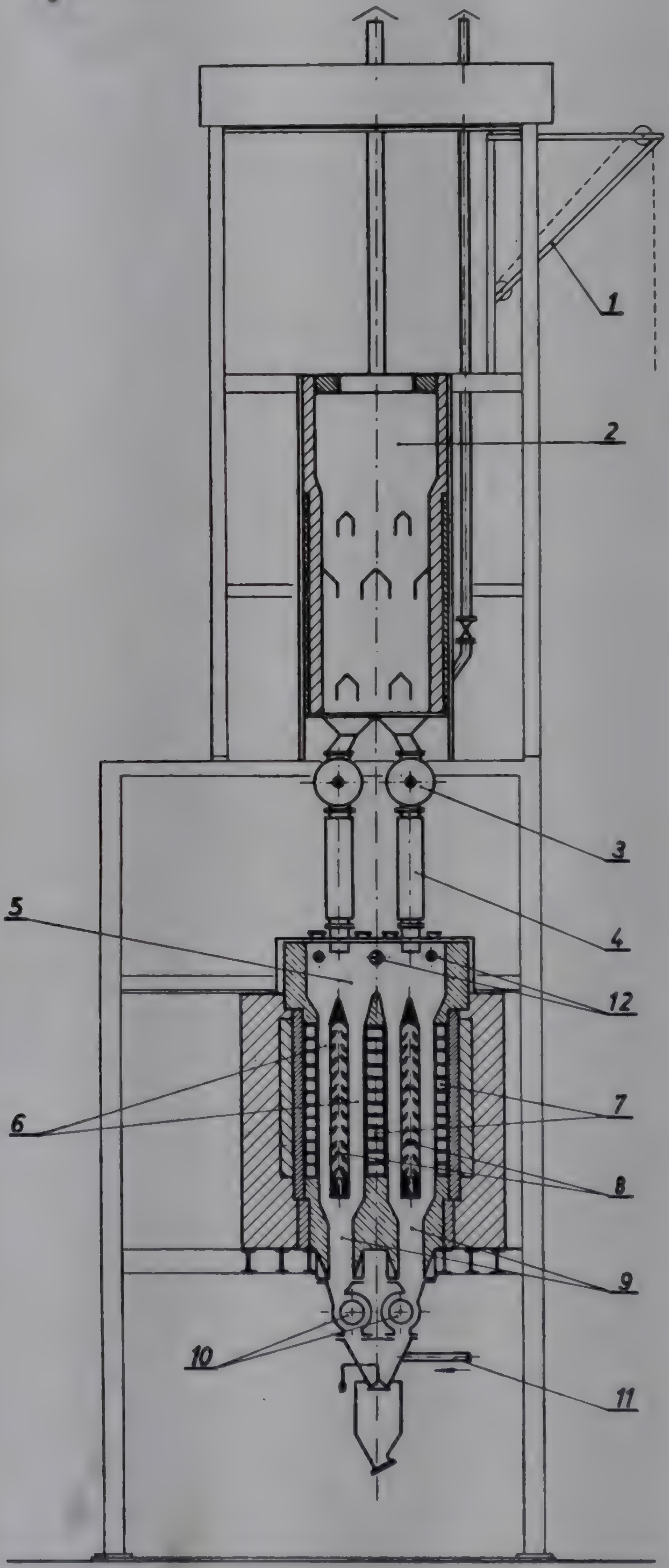

FIG. 1—CROSS-SECTION OF THE CARBONIZING PLANT: (1) Elevator (2) Dryer (3) Z-lock (4) Chute (5) Predistillation chamber (6) Coking chamber (7) Heating flues (8) Louvre-type gas ducts (9) Coke cooling chamber (10) Coke discharging device (11) Introduction of carrier gas (12) Exit of product and carrier gas

in the middle, and the coke-cooling chamber situated below. Underneath the coke-cooling chamber is the coke-discharging device which, in turn, is connected to the coke bunker fitted with a double closure. The rate of the coke discharge and consequently, the operation of the oven are controlled by the adjustment of the speed of rotation of the coke discharging device.

The coke is cooled with carrier gas, which is recirculated and introduced into the zone below the coke discharging device in a proportion of 0.5 to 0.6 Nm^3 per kilogram of coke.

It has been earlier observed that a substantial gas-resistance is built up in the coal-coke layer of vertical chamber ovens causing gas losses through the heated walls. To deal with this situation, a vertical duct system, arranged in louvre-form and resting on a support, is constructed in the middle vertical plane of the oven, through which the gas, after passage through the coke-cooling chamber, is conducted directly to the predistillation unit.

Coal in the oven chambers begins to loosen up by carbonization alongside the walls. Gas evolved from the coal leaves alongside the walls, where least resistance is encountered. Propagation of heat towards the centre of the oven has thus to take place in a direction opposite to that of product gas, increasing thereby the time and hence, the heat requirement of carbonization. But in this new oven used, heat from the heated walls flows in the same direction as the produced gas which, entering through the slits of the louvre-like vertical ducts, is mixed with the carrier gas and conveyed to the predistillation unit. This gas mixture preheats the entering coal, from about 100° to about 400°C., before it enters the carbonizing chamber. This system utilizes the heat content of the coke for the predistillation of coal through the medium of the carrier gas.

A final temperature of about 900°C. may be assumed to have been attained by the coke since the temperature in the heating flues is 1000°C. to 1200°C. The gaseous products leave the predistillation unit at a temperature of 150°-200°C. and the temperature of the discharged coke varies between 100° and 150°C.

Equipment is provided for the preparation of coal to be carbonized. Gas leaving the oven is passed through a condensation unit for the removal of byproducts. Coke is discharged into coke cars.

The instrumentation of the oven and the attached equipment is adequate for the measurement of all the required variables.

The characteristics of coals carbonized in the pilot plant and the analyses and yields of the products obtained are summarized in Table 1. These data were obtained from experiments carried out in 1958.

While brown coal gives a small sized crumbling coke, the coke from flame coal retains more or less the original grain size of the coal and possesses a high Micum-strength (about 70). This coke can be used directly, without prior briquetting. For the production of domestic coke with an ash

TABLE 1—TYPICAL DATA ON CARBONIZATION OF DIFFERENT COALS

Coal	Origin	Lignite from Gyongyos	Brown coal from Berente	Brown coal from Tata	Polish flame coal
	Grain size, mm.	20-120	40-80	5-20	10-20
	Moisture, %	42·80	23·50	12·49	5·37
	Ash, %	12·58	19·12	12·24	13·07
	Calorific value, kcal./kg.	2259	3362	5093	6011
Coke	Yield, %	32·2	45·3	46·2	63·8
	Grain size above 5 mm., %	35·0	52·3	45·0	83·5
	Ash (dry basis), %	41·6	38·7	25·8	21·2
	Volatiles, %	1·5	3·5	1·7	0·7
Gas	Gas yield, Nm^3/tonne	172	210	265	275
	Analysis:				
	H_2S, %	4·0	6·1	5·4	0·4
	CO_2, %	15·3	12·0	9·0	1·9
	C_mH_n, %	0·9	1·1	1·3	0·8
	CO, %	23·2	19·4	17·8	15·4
	CH_4, %	21·1	28·3	25·4	24·8
	H_2, %	31·3	33·7	32·5	52·7
	Gross calorific value, kcal./Nm^3	4082	4225	4525	4609
	Net calorific value, kcal./Nm^3	3695	3812	4080	4103
	Specific weight, g./Nm^3	900	853	822	525
Tar	Yield/coal, %	3·6	4·3	9·6	8·1
	Per cent of the Fischer-analysis	103·5	86·8	83·4	81·0

content of not more than 20 per cent coal suitably prepared should be used.

The remarkably low heat requirement of carbonization can be attributed primarily to the fact, that almost all the heat content of the glowing coke is returned to the coking process, and to the fact, that gas and by-products leave the oven (Fig. 1, No. 12) at a temperature of 110°-180°C. and the temperature of the discharged flue gas developed from the heating gas, being low (210°-270°C.). The louvre-like vertical ducts, built in the middle vertical plane of the coking oven also contribute towards this.

For the sake of comparison, it may be stated that the heat requirement of drying and coking of 1 kg. of brown coal briquette with a moisture content of 15 per cent in a Lurgi-type carrier gas carbonizing oven is as low as 290 kcal. In Hungary, the heat requirement of brown coal (30 per cent moisture content) carbonized in a Lurgi-type oven (50 tons per day capacity) amounted to 390 kcal./kg., according to the data collected in 1927. In the gigantic carbonizing works of Most in Czechoslovakia, consisting of 80 Lurgi-type carrier gas twin-ovens, each twin-oven has a daily capacity of 250 tons of brown coal of 28 per cent moisture content. In this unit the heat requirement for drying and coking of coal is 560 kcal./kg. The heat required for carbonizing at 650°C. brown coal of about 14 per cent moisture content in a Kosag-Geissen oven amounts to 480 kcal./kg. The heat requirement of caking coal varies between 520 and 1000 kcal./kg., depending on the system and the size of the oven.

To facilitate comparison, the heat requirement of carbonization calculated on coke basis is also given in Table 2. Specific performances, though obtained in an oven of relatively small size, are quite satisfactory.

The oven was dismantled after the experiments, and no defects were found either from the point of view of operation or that of construction. On the basis of the experience gained, the oven was rebuilt with no substantial modifications. Only some minor changes like the form of the ceramic bricks, the slope of the inclined planes in the predistillation chamber, etc. were effected. Further experiments were next carried out in 1960. The more important results are summarized in Table 3.

TABLE 2—OPERATIONAL DATA AND SPECIFIC PERFORMANCE

Origin of coal	Gyongyos	Berente	Tata	Polish
Heat requirements per kg. of coal, kcal.				
Gas used for coal drying	254·2	168·6	105·2	62·5
Gas used for coking	65·4	87·6	121·6	129·8
Total	319·6	256·2	226·8	192·3
Gas used for water evaporation, kcal./kg. of water	638·9	803·0	867·3	2498·0
Heat requirements per kg. of coke, kcal.				
Heat content of gas used in the dryer	790·1	372·2	228·3	97·8
Heat content of gas used in the oven	203·2	193·3	263·1	203·2
Total	993·3	565·5	491·4	201·0
Oven load per heated wall surface, kg./sq.m./hr				
Charged coal	59·1	56·8	37·9	26·8
Water-free coal	33·4	43·5	33·0	25·3
Coke	19·0	25·7	17·5	17·1
Calories, kcal./sq.m./hr	3860	4970	4609	3475

TABLE 3—RESULTS OF CARBONIZATION UNDER MODIFIED CONDITIONS (1960)

Coal origin	Tata	Tata	Tata	Tata	Dorog	Berente	Gyongyos	Polish	Polish
Grain size, mm.	6-20	6-20	20-40	5-60	6-20	lumpy	lumpy	5-20	5-40
Moisture content, %	11·96	11·92	12·50	12·38	13·28	22·46	49·00	3·34	4·61
Ash content, %	13·77	12·16	17·53	9·65	16·02	19·02	14·67	13·83	10·36
Calorific value, kcal./kg.	5008	5008	4718	5227	4651	3510	1786	6254	5592
Coal charged, ton/day	7·51	12·24	16·16	15·75	14·42	17·18	15·45	11·11	7·53
Coke									
Yield, %	50·5	49·2	53·0	52·0	50·6	44·6	32·6	66·6	72·3
Ash, %	26·05	24·16	26·62	22·11	35·22	27·30	44·60	17·81	14·65
Volatiles, %	1·04	3·02	12·89	3·50	6·15	1·95	1·12	0·85	1·00
Gas									
Yield, Nm^3/t	253	234	173	275	238	168	142	253	273
Specific weight $g./Nm^3$	837	917	985	920	941	818	915	513	513
Gross calorific value, $kcal./Nm^3$	4030	4351	3838	5424	3681	4328	3314	4334	4361
Net calorific value, $kcal./Nm^3$	3631	3928	3471	4901	3319	3900	3001	3845	3870
H_2S, %	3·3	4·1	3·9	5·5	2·8	5·3	2·3	0·2	0·1
CO_2, %	8·7	11·3	14·6	13·9	12·4	10·0	12·8	2·4	2·1
Heating flue temp., °C.									
Top	866	800	774	947	993	1040	943	1110	1025
Bottom	1096	1008	901	1030	1087	1146	1128	1090	1083
Heat requirement, kcal./kg. of coke									
Drying	129	125	145	157	136	190	300	142	170
Coking	189	123	135	143	171	125	127	158	204
Total	318	248	280	300	307	315	427	300	374

CARBONIZATION UNDER MODIFIED CONDITIONS (1960)

The first four experiments were conducted in which the oven was operated at a daily load of 7·5, 12·2, 16·2 and 15·8 tonnes respectively to study the performance of the oven. Unfortunately, the heating of the oven got out of control, as manifested primarily in the temperature of the heating flues, in the heat requirement of carbonization and in the volatile content of the coke.

By maintaining a flue temperature of about 1000°C. at the top and about 1150°C. at the bottom, and by operating the oven with coal from Tata or Dorog (with a moisture content of 13-15 per cent), at a load of about 16 tons of coal per day coke with a volatile matter of 1-3 per cent can be obtained. The oven is found to be very flexible to meet seasonal (i.e. summer and winter) gas demand.

When coal and lignite of Berente and Gyongyos, which have a higher moisture content, are processed in the plant (Experiments No. 6 and 7) the dryer forms the bottleneck.

Heat requirement of coking was about 5-10 per cent more than that found in the experiments of 1958. This increase is to be attributed primarily to the dryer, where the outlet temperature of the gas had to be increased. Neither was the heat content of the discharged flue gases utilized to such a degree as before, and heating and excess air were not always regulated to their optimum value. The processed Polish flame coal had a coking capacity corresponding to a Roga-index of about 15. With this coal, caking in the predistillation chamber and operating troubles in the oven were encountered during the experiments carried out in 1958.

The caking property of coal could be reduced by keeping it for a definite period at elevated temperature, not exceeding, however, the temperature at which carbonization begins. The temperature of the carrier gas entering the dryer was maintained at 244°-250°C. and its oxygen content kept below 1·2 per cent, to eliminate the hazard of spontaneous combustion. The longer residence time of the coal in the dryer was attained by operating the oven at a slower rate. Accordingly, a relatively small volume of carrier gas was circulated (Experiments No. 8 and 9).

As a result no operational difficulties were encountered in the experiments conducted with Polish flame coal. The thermal treatment of coal in the dryer required, naturally, about 100 kcal./kg. more than simple drying. In relation to the lower throughput, the heat of coking and the total heat requirements were also higher (300 and 374 kcal./kg. respectively) as compared to the value of 200 kcal./kg. obtained in 1958.

When coal (from Tata) was fed at a low load of 7·5 tonnes/day, the time taken for the passage of the coal through the dryer was about 20-22 hr. At high load this period amounted only to about 10 hr, and, at the same time, the material passed in about 13 hr through the oven, the total time of travel amounting thus to 23-24 hr. Depending on the volume of the carrier gas, varying between 0·5 and 1·0 Nm^3/kg. of coke, the temperature of the discharged coke varied between 80 and 200°C. The pressure difference between the incoming and outgoing gases caused by the resistance offered by the material in the oven varied between 5 and 47 mm. water guage, depending on the experimental conditions, but was generally in the range of 10-20 mm.

The tar obtained was a primary tar, its condition of formation satisfying the requirements of low temperature carbonization. Tar yields as obtained in the original experiments (1958) and shown in Table 1 varied between 80 and 100 per cent of the value obtained by the Fischer distillation, and in some cases even more. The same results were obtained in the experiments carried out under modified conditions in 1960, but on account of the thermal pretreatment, the tar yield of the Polish flame coal was only 60-70 per cent of the Fischer value.

The oven was dismantled at the end of these experiments and the interior of the oven was found to be very satisfactory. The ducts of the louvre construction were clean. All the modifications, made when rebuilding the oven after the experiments in 1958, proved to be advantageous and satisfactory.

If this oven is to be constructed on an industrial scale, its exterior can be very similar to that of the Lurgi carrier gas carbonization unit. One unit could be designed for a daily capacity of 120-150 tonnes of coal with a moisture content of about 15 per cent (one twin-unit for 250-300 tonnes). For the sake of comparison, it may be mentioned that 5000-6000 tonnes per day of coal (moisture content 28 per cent) are processed in the 20 twin-ovens of the carbonizing plant of Most (Czechoslovakia), each shift requiring nine men, out of which one is the shift leader, two are foremen and seven mechanics. Power consumption is 11 Kwh/tonne of coal and water consumption 8-10 m^3/tonne of coal. The calorific value of the product gas is 1700-1800 kcal./Nm^3.

The advantages of the oven designed and operated at this Institute are as follows:

1. The heat requirement of the oven for drying and coking is substantially less, about 20-50 per cent of that of the ovens known up to now.
2. Both high and low temperature carbonization of coal can be carried out in this oven. No hazard of spontaneous combustion is encountered with coke of low volatile matter.
3. The coke is discharged from the oven after dry quenching at a temperature of about 150°C.
4. The gas produced has a high calorific value, and is suitable for town gas manufacture.
5. The loading of the oven can be altered in the ratio of 1 to 2 and the operation is flexible and can be adjusted to meet the actual gas demand.

6. Its power and water consumption will be less than that of the Lurgi-type oven, since relatively small volume of carrier gas has to be circulated in the coking section.

7. The labour requirement of the oven will be about the same as that of the Lurgi-type oven.

PROBLEM OF BRIQUETTE COKE MANUFACTURE

No satisfactory solution has been found up to now for the carbonization of brown coal briquettes on large scale. The Institute therefore built an oven according to the Hungarian Patent 105376, granted in 1931, and operated it during the experiments in 1960.

Briquettes prepared from coke with pitch soften on heating, and are deformed in thicker layers under their own weight. This trouble can be eliminated by carbonizing the briquettes in a vertical chamber furnace with the so-called stepwise charging technology, as described in the above mentioned patent. A vertical chamber furnace was built for this purpose with the following dimensions: width, 200-250 mm.; length, 1120 mm.; height, 3000 mm.; volume, 0·756 m³. The chamber was surrounded on two sides by heating flues, and recuperation was provided. A coke cooling chamber of equal volume was installed below this chamber, followed by a coke discharging device. A condensation unit was connected to the chamber.

When operating according to the stepwise charging method, a certain quantity of briquettes is discharged from the fully charged furnace so that the upper level of the briquettes may sink by 80 cm. below the top of the chamber. Raw briquettes are charged then into this void space. This procedure may be repeated at intervals of about an hour, when a hard crust is formed on the refilled briquettes. To improve the efficiency and the heat economy of the process, 0·4-0·7 m³. of carrier gas per kilogram of briquette coke was introduced, both for cooling the briquettes produced and for accelerating the heating of the incoming briquettes.

Since, the soundness of the process had to be established, data like the most favourable height of layer and the time of the individual charging steps, data on the cooling of the briquettes, the volume of carrier gas, the coking time, the heat requirement, etc. had to be determined.

Coke from brown coals of higher rank, crushed in a roller mill to a grain size below 3 mm. was used for the manufacture of the briquettes. The pitch (6 per cent) and caking coal (12 per cent) of swelling index 2·5, consisting chiefly of a grain size below 1 mm. were admixed with the briquettes. The mixture was briquetted on an industrial roller-press. The ovoid briquettes of 61 × 48 × 33 mm. dimension weighed 60-65 g. with a bulk density of 800 kg./m³. The cushion briquettes of 55 × 36 × 25 mm. dimension weighed about 46 g.

The most important experimental results obtained with the briquette coking furnace are summarized in Table 4.

The following conclusions may be drawn, from the operation of the plant.

1. The stepwise charging technique proved to be very satisfactory for coking of briquettes, eliminating embedding of the briquettes in coke.
2. For a given chamber width of 200-250 mm., dense layers of briquette may be charged without the risk of their deformation on account of their arching.
3. The charging period can be reduced to less than 45 min.

TABLE 4—RESULTS OF BRIQUETTE CARBONIZATION

SERIAL NO. OF EXPERIMENTS	B/II	B/IV	B/V	B/VII	B/VIII
Raw briquette					
Bulk density, kg./m.^{3}	805	800	800	827	773
Point strength, kg.	134	114	89	97	114
Moisture, %	5·3	4·7	..	5·8	5·0
Ash, %	20·8	22·3	..	21·9	21·9
Briquette coke					
Bulk density, kg./m.^{3}	694	666	675	666	650
Point strength, kg.	114	151	197	151	168
Shatter test 20 mm., %	85	83	72	89	60
Drum test 20 mm., %	35	42	27	52	14
Ash (dry basis), %	23·9	25·3	26·2	25·9	26·2
Volatiles, %	3·4	1·3	3·5	3·5	2·6
Calorific value, kcal./kg.	6066	6140	6153	6129	6174
Weight of one charge, kg.	150	150	200	100	120
Briquettes charged, kg./day	3600	3600	3200	3200	2880
Height of one charge, mm.	804	804	1070	528	674
Period of charging, min.	60	60	90	45	60
Coking time, min.	249	249	270	280	300
Travelling time, min.	507	507	563	585	610
Yield of briquettes, %	83·0	80·8	82·9	81·3	80·4
Volume of carrier gas, Nm^3/kg.	0·381	0·534	0·539	0·668	0·675

4. The coking time can be reduced to less than 4 hr, provided a higher temperature is maintained in the heating flues.

The heat requirement of carbonizing, when charging 150 kg. of briquettes per hour, was found to be about 380 kcal./hr and increases to more than 500 kcal./hr on reducing the throughput rate to 120 kg./hr.

The discharged coke has a temperature of about 200°C. at the bottom and about 520°C. at the top of the heap. This relatively high temperature is chiefly due to the small volume of carrier gas and to the short cooling time.

When circulating gas evolved from the briquettes alone as carrier gas (without the admixture of carbonization gas), the organic sulphur content was 48 g./100 Nm^3, the upper limit permissible in town gas. In experiments where the coal carbonization gas was introduced into the briquette coking furnace as carrier gas, a very slight decrease in organic sulphur content was observed only when the hydrogen sulphide content of the gas was low. At higher hydrogen sulphide concentrations, a slight increase of organic sulphur content occurred even at the expense of the former. A slight reduction in the CO_2 and CH_4 content, and an increase in the CO and H_2 content could be noticed. Thus a substantial part of hydrogen sulphide needs to be removed from the coal carbonization gas, if the latter is to be used as carrier gas in the briquette furnace.

The briquette coke is of suitable strength for domestic purposes, as shown by the data in Table 4. Only the abrasion strength may be objectionable, which indicates the degree of crumbling that may take place during transportation and handling. In the present experiments no stress was laid on the quality of the briquettes, since attention was centred chiefly on the coking technology and the operation of the furnace. Earlier investigations, concerning the quality of the briquettes, indicate that briquettes of 300 kg./sq. cm. compression strength and of high abrasion resistance may be readily obtained by proper selection of the quality (including the particle size) and quantity of the pitch and the caking coal.

The reactivity of briquette coke was found to be 146, that of the coke of Polish flame coal 180. Both the cokes were tried for long durations in different kinds of domestic appliances. They proved in all cases to be readily combustible efficient smokeless fuels.

The gas produced in both furnaces is a suitable basic material for the manufacture of town gas.

The data obtained from these experiments form a suitable basis for the designing of industrial ovens of any desired capacity. Besides offering a solution to the problem of the coking of Hungarian brown coals and non-caking coals and of the production of briquette coke, the results obtained will prove useful also for other countries as well.

The Combined Heating Surface/ Spuelgas Process—Koppers System for Producing Domestic Coke

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A description of the heating surface/spuelgas process—Koppers system is given and the special advantage of the process indicated. One of these is the production of high Btu gas which as surplus gas is most suitable for distribution to towns and industries. Such gas production can be very suitably adapted to the increasing gas requirement. The calorific value of gas can also be adjusted to a great extent. The oven system is suitable for low temperature carbonization as well as medium and high temperature carbonization. Servicing of the plant is simple, and the low heat consumption results in an economic mode of operation with low production costs for coke, gas and tar products. As a result of careful handling of tar vapours in the oven chambers, byproducts of good quality are obtained. It is suggested that the process is very suitable for production of domestic coke in India.

It has been known for some time that the fuel requirements of Indian households are still for the greater part covered by the use of dried cow dung and wood. By thus depriving agricultural land of natural fertilizers, and by the vast removal of timber with its known consequences such as reducing the land to steppe, erosion of fertile soil, etc. the increase of agricultural crops which are necessary to India is hampered.

Indian technicians have therefore been considering the provision of a suitable substitute fuel to counteract the dangers arising from the use of cowdung and wood. The main requirements of such a substitute fuel are, in addition to a low price, smokeless combustion in simple Indian fireplaces as well as easy ignitability and good reactivity. These requirements can best be fulfilled by lumpy coke obtained from carbonization of hard coal or brown coal at low temperatures. A coke of this kind still has about 6-10 per cent volatile matter and smokeless combustion is possible with a low ignition point.

India has comparatively large deposits of coal. Owing to their caking characteristics, only part of these coals are usable for the production of normal high temperature coke required for large scale iron and steel production. The greatest part of Indian coal deposits consist of geologically young coals without the required caking property. These non-caking or poorly caking coals are a natural choice for the production of smokeless fuel at comparatively low temperatures. In addition to the production of coke for domestic use, numerous products can also be recovered from the tar and liquor obtained during low temperature carbonization (l.t.c.), such as gasoline, diesel oil, creosote and phenol. There is a great demand for these products in India.

The importance of l.t.c. industry has been recognized in some responsible quarters in India who are proposing the establishment of a number of large l.t.c. plants in various parts of the country based on local coal deposits. The capacity of each of these plants is likely to be in the first instance 1000 to 2000 tons of coal per day. It is possible that the construction of an l.t.c. plant of this size will result in drawing a number of other industries to the vicinity of the plant, whereby the economy will correspondingly improve.

HEATING SURFACE/SPUELGAS PROCESS, KOPPERS SYSTEM

Koppers have dealt with the processing of coal for many decades and turned their attention very early to the carbonization of coal at comparatively low temperatures. In the period between the two world wars Koppers erected a large number of plants partly with horizontal and partly with vertical ovens for medium and low temperature carbonization of coals with different characteristics. The continuously operating vertical chamber oven system, normally constructed at gasworks, has proved particularly suitable for l.t.c.

The heat required for carbonizing the coal can be applied to the charged material by the externally heated chamber wall surfaces, i.e. heat conduction, or by a heated gaseous medium which flows through the charge, i.e. by convection. The first type of heat conduction is well known in coke ovens and gasworks. The second type of heat transfer by means of hot gases (spuelgas) was used by Koppers as far back as 1935-37 for a large plant which was constructed for Braunkohle-Benzin-AG in Central Germany. This plant which was intended to produce a synthesis gas of a certain composition showed very good operating results under the conditions prevailing then. Thus Koppers have collected valuable experience with both types of heat transfer.

A combination of the two types of heating was used many years ago in the erection of a large plant. In 1933 a continuously operating vertical chamber plant with 16 ovens to start with was erected by Koppers in Japan and high ash, high volatile nut coal was carbonized. To fulfil the requirements of the customer for a gas with a high carbon monoxide and hydrogen content for the synthesis, steam was additionally introduced into the lower part of the oven chambers. This steam was converted by the glowing coke into CO and H_2. On account of the steam introduced and water gas formed, heat transfer from the heating walls of the ceramic oven to the coal was very much improved by additional convection. A considerable increase of the throughput capacity of an oven fed with steam and spuelgas as compared to an oven using only the heating surface system, was thus achieved. In the following years the Japanese plant was extended to 140 oven chambers which goes to prove that the plant completely fulfilled its expectations.

Based on the experience and knowledge gathered in the above mentioned plant, Koppers developed a carbonization process which represented a combination of pure heating surface and hot spuelgas systems. The continuously operating vertical oven Koppers system which has proved its efficiency at gasworks in Germany and elsewhere was used as a basic principle. This oven of a suitable size and constructed for l.t.c. operation is fitted with additional equipment for charging spuelgases.

In the years before the last World War and during the early part of the war l.t.c. of coal assumed great importance in Germany. In addition to the production of l.t. coke as fuel there was a demand for the production of tar of special quality. At this time Koppers made extensive tests with a vertical chamber oven plant in Upper Silesia. This plant was previously fitted with additional equipment for charging spuelgas. The tests showed very good results regarding the products recovered and the performance of the oven. Consequently, in 1942 the Upper Silesian Mine Administration gave Koppers an order to construct 90 ovens employing the combined heating surface/spuelgas process. This plant was designed for a daily throughput of 2740 tons of lump coal.

The mode of operation of the combined heating surface/spuelgas process is described with reference to the sectional view in Fig. 1. The coal bunker (1) is situated above the oven and the coal is fed through a charging device (2) into the oven chamber. The coal moves slowly and continuously through the oven chamber towards the bottom. The coke forming in the chamber is conveyed by an extractor (4) fitted at the bottom end to a collecting vessel (5).

The coke is thrown from the collecting vessel by a special sluice onto the coke wharf (6). The coke wharf is fitted with final quenching equipment to give the coke the required moisture content. In front of the coke wharf a conveyor belt is installed which passes the coke to a screening unit with connected loading equipment.

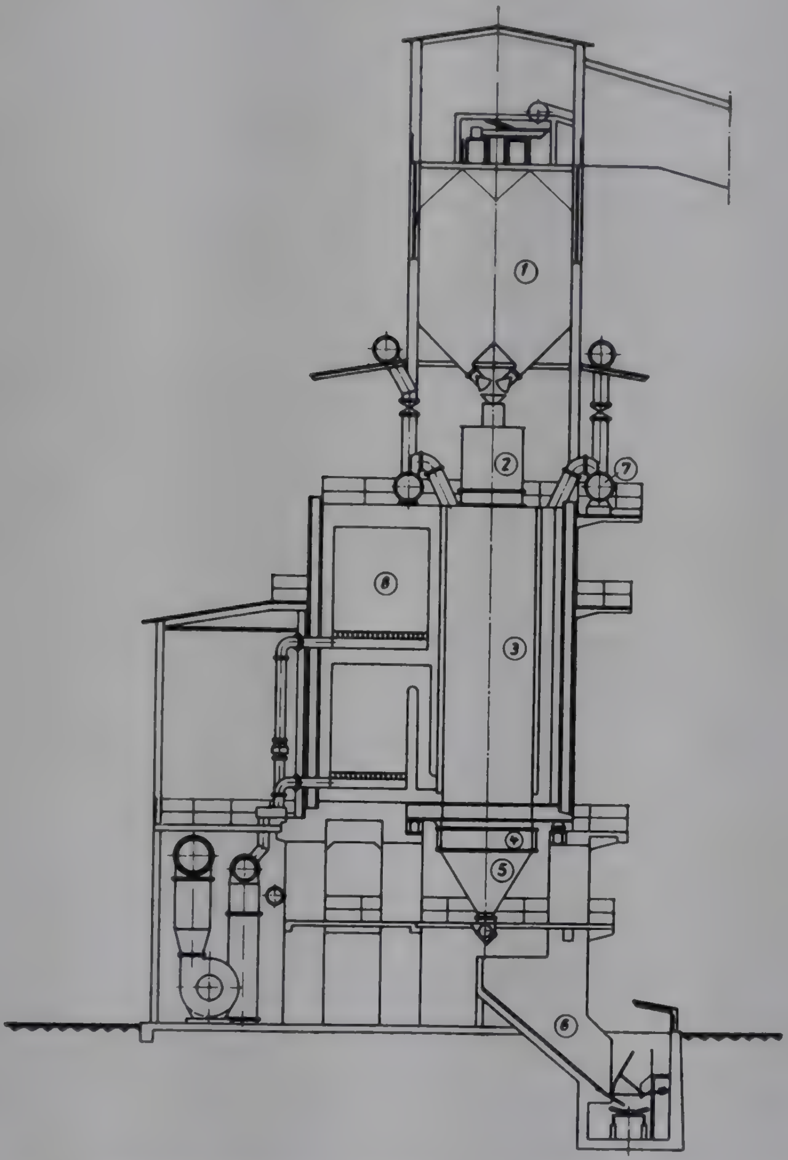

Fig. 1—Sectional view of the combined heating surface/spuelgas process—Koppers system: (1) Coal bunker (2) Changing device (3) Oven chamber (4) Extractor (5) Collecting vessel (6) Coke wharf (7) Gas collecting main (8) Regenerators

Charging of the coal and discharging of the coke take place every 60 min. The movement of the coal and coke in the chamber is continuous. If required, charging and discharging may be done completely automatically.

Heat is conducted to the charge by the heating walls and to achieve a high throughput, cold spuelgas is introduced at the bottom of the chamber. A prerequisite for charging spuelgas is the use of a non-caking or poorly caking lump coal in the form of nuts or briquettes to ensure proper flow of the spuelgas through the charged material. The lump coal or briquettes must possess sufficient strength to avoid disintegration in the chamber which would hinder circulation of the spuelgas. Obviously, the melting point of the coal ash should be sufficiently high and above the temperature at the heating walls. In general the melting point of ash from the Indian coals is so high that clinkering of the ash on the oven walls need not be feared.

The coke-oven gas is cooled and detarred in the gas-treatment unit and is used normally as spuelgas. By feeding cold spuelgas to the lower part of the oven, the coke produced is cooled and the sensible heat of the coke is extensively returned to the carbonizing process. For further quenching the coke water may be injected into the extraction equipment, or the coke may be indirectly cooled below the oven chamber so that a quenched coke can be extracted. The spuelgas introduced rises in the oven chamber, and improves heat transfer to the coal by additional convection thus leading to an even distribution of the volatile constituents in the coke and a more careful carbonization of the coal regarding the ensuing tar vapours. The spuelgas mixes with the coke oven gas released and leaves the chamber at the top after having transferred most of its sensible heat to the coal. The gas is led to the gas-collecting main (7) and from there to the gas treatment unit. As a result of carefully handling the tar vapours in the top part of the oven and by the use of spuelgas, the recovered tar corresponds approximately to the tar yielded in a pure spuelgas process. In l.t.c. tests made so far, a tar yield of about 85 per cent of the Fischer assay yield was obtained.

The oven chambers of large plants have the approximate dimensions: height, 11·5 m.; length, 3·5 m.; mean width, 0·3 m.

The walls of the oven chambers are made completely of standard silica material. By strengthening the heating walls at the top part of the chamber, the chamber wall temperature can be lowered in this region to preserve the tar vapours. The temperature in the heating flues can be kept sufficiently high to ensure a good passage of heat in the lower and centre part of the oven chamber. The capacity of an oven chamber is normally over 40 tons per day and by putting several oven chambers in a block, oven units of a greater capacity are obtained.

The chambers are regeneratively heated and the vertical heating flues are alternatively charged from top to bottom and from bottom to top. The heating system and basic design of the oven are similar to the continuously operating vertical chamber oven, Koppers system. The regenerators (8) are situated at the side of the oven chambers and are made of fireclay material and provided with a suitable filler. By the regenerative heating and by quenching the coke within the oven system an exceptionally low heat consumption is attained in the process.

The heating surface/spuelgas oven, Koppers system, can be erected as a combination oven for optional heating with lean gas which would be obtained from producers or by means of the l.t.c. gas produced in the ovens. This results in a good adaptability of the oven for the production of town gas to which reference will be made later. The carbonization temperature and the throughput capacity of the ovens can be adjusted within

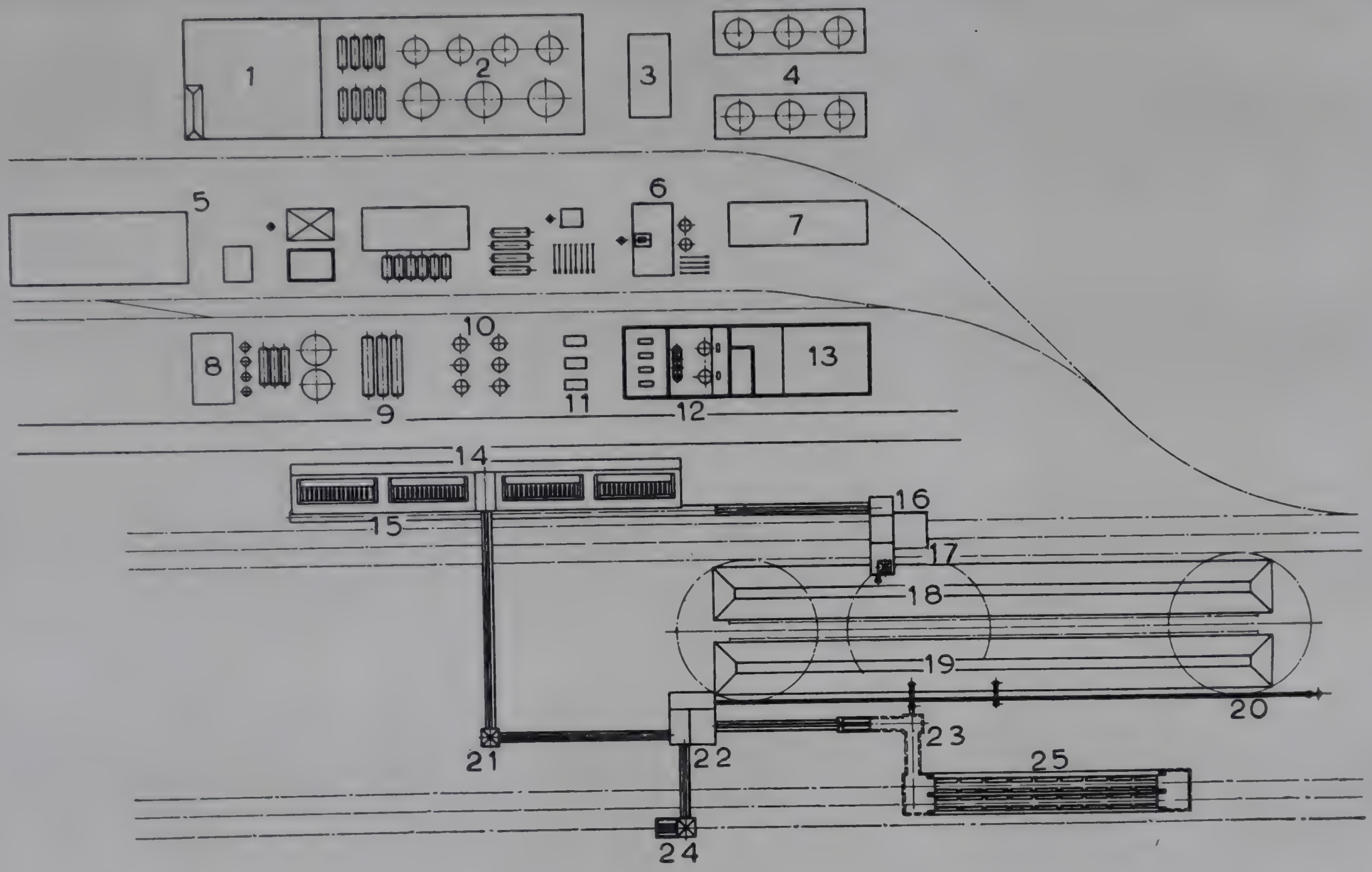

FIG. 2—PLAN OF COMPLETE L. T. C. PLANT AND SECONDARY UNITS: (1) Filling station with storage for barrels (2) Storage tanks for products (3) Pumph house (4) Cooling water recooling plant (5) Distillation plant and tar acid recovery (6) Benzole recovery plant (7) Hydrogen sulphide dry absorption plant (8) Waste water dephenolizing plant (9) Flushing water and condensate treating plant (10) Electrostatic tar precipitators (11) Primary gas coolers (12) Gas exhausters and blowers (13) Ammonia saturator plant (14) L.t.c. plant (15) Coke wharfs (16) Screening station (17) Reclaiming (18) Coal and coke storage (19) Coal storage (20) Storage charging and reclaiming belt (21) Junction tower (22) Crusher station (23) Discharge car (24) Coal to the power station (25) Pit bunker

very wide limits and it is quite possible to change over the ovens from low to medium temperature carbonization or even to high temperature carbonization, depending on the products in demand.

The plant must be provided with the necessary secondary units such as coal storage and coal handling units and equipment for transporting and grading the coke produced. Further, a gas treatment unit will be necessary for processing the tar and other oils.

Fig. 2 shows a plan view of a complete l.t.c. plant to produce domestic coke with all secondary units. Besides the equipment for coal and coke handling and for gas treatment, units have been provided for processing tar, including tar acid recovery, gasoline recovery, ammonia production, and a plant for dephenolizing waste liquor.

According to local conditions it may be advantageous to combine an l.t.c. plant producing domestic coke with a thermal power station based on coal. In such cases the supplied coal could be graded on a screen, the lump coal of about 1-3 in. being used in the l.t.c. plant to produce domestic coke, and the coal below 1 in. supplied to the power station. If necessary, briquettes made from the small coal can also be considered for charging to the l.t.c. plant.

The combined heating surface/spuelgas process incorporates the advantages of the spuelgas process such as:

> (*a*) high throughput capacity, (*b*) good heat transfer to the coal, and thus a lower heat requirement, and (*c*) small retention time of the tar vapours in the chamber, thus minimum cracking, and high tar yield, with the great advantage of the heating surface process, i.e. essentially better gas quality as compared to the pure spuelgas process.

With the combined heating surface/spuelgas process, a gas is yielded with an Hs of about 4500-5300 kcal./Nm^3 (470-555 Btu/cu. ft) which can be used as normal town gas. As against this a gas with a much lower calorific value of about 1100-1700 kcal./Nm^3 (115-180 Btu/cu. ft) is yielded in the plain spuelgas process, because it is diluted by combustion gases.

The calorific value of the gas obtained with the heating surface/spuelgas process can be easily adjusted by the introduction of steam and the formation of water gas in the lower part of the oven chambers. Thus, a considerable increase in the gas yield and in the calorific value is possible. The gas yield and the calorific value can also be altered to a great extent by changing the carbonization temperature.

In future, in India also, production of gas as also of coke and tar will assume an increased importance, as in other industrialized countries. This can be seen from Indian press reports (e.g. The Times of India of November 13, 1959). Considering the importance of gas production both for industrial and for domestic use, the combined heating surface/spuelgas process offers many advantages. It is profitable to convey a high Btu gas

TABLE 1—PROJECT DATA FOR AN L.T.C. PLANT PROCESSING JAMBAD-BOWLAH COAL AT 600°C. BY KOPPERS COMBINED HEATING SURFACE/SPUELGAS PROCESS

Coal input (5% moisture), tons/day	2,000
L.t. coke output (5% moisture), tons/day	1,400
Gas production (gross calorific value=5250 kcal./Nm^3), Nm^3/day	2,88,000
Gas for heating, Nm^3/day	1,41,500
Surplus gas, Nm^3/day	1,46,500
L.t. tar yield, tons/day	190
Light oil, 102°-170°C. (3·7%), tons/day	7
Middle oil, 170°-230°C. (17·6%), tons/day	33·4
Creosote oil, 230°-230°C. (13·2%), tons/day	25
Anthracene oil, 270°-360°C. (31·0%), tons/day	59
Gasoline from the gas, tons/day	15·2
Ammonium sulphate, tons/day	19
L.t. liquor, tons/day	275
Phenol from liquor, tons/day	11
Proximate analysis of L.T. coke	
Moisture, %	5
Ash, %	17-18
Volatile matter, %	8-10
Fixed carbon, %	68-70

Gas analysis (after gasoline and H_2S removal), vol. wt %

CO_2	14·2
C_nH_m	2·4
O_2	0·7
CO	13·8
H_2	27·7
CH_4	37·5
N_2	3·7
C.V. (gross), kcal./Nm^3	5250
C.V. (net), kcal./Nm^3	4700
Density (air=1)	0·64

over long distances, and in all industrialized countries extensive pipeline systems have been constructed for supplying gas over long distances. When erecting a l.t.c. plant of the desired capacity, it is to be expected that other industries will develop in the neighbourhood providing ready market for gas of town gas quality.

With the process described, the gas yield can be adjusted to the prevailing demand. In the beginning, if the demand for gas is not so great, it is recommended that the coal be carbonized to a lesser degree, to give somewhat higher yield of easily combustible coke with about 10 per cent volatile matter besides higher tar yields. Of the l.t.c. gas produced under these conditions it is assumed that about 50 per cent will be required for heating the ovens and the remainder can be sold as town gas for industrial and domestic uses.

When erecting a l.t.c. plant for a daily throughput of 2000 tons of Jambad-Bowlah coal, about 288,000 Nm^3 gas with an Hs of 5250 kcal./Nm^3 will be yielded at a carbonization temperature of about 600°C. Of this 141,500 Nm^3 will be required for heating the ovens and the remaining 146,500 Nm^3 of high Btu gas will be available for other purposes (Table 1). This gas can be brought to the required calorific value by admixing other gases such as producer gas, blast furnace gas, etc. In Europe, town gas is supplied to the consumer with a heating value of about 4200 kcal./Nm^3. For larger gas requirements it is possible to heat the ovens with producer gas made from coke or suitable coal, so that the entire gas from the ovens will be available for supply as town gas. In this way the volume of surplus gas can be practically doubled. Should there be greater demand for gas, a small increase in the carbonization temperature in the oven can further improve the output of gas.

A further advantage of the combined heating surface/spuelgas process needs to be mentioned. The plain spuelgas process requires an absolutely non-caking coal as feedstock, as otherwise grape-like formations may occur in the oven which hinder the passage of the spuelgas and prevent the coal from dropping at the distributors for feeding the spuelgas. The continuously operating vertical chamber oven used with the heating surface/spuelgas process is not prone to difficulties of this type, because there are no installations to cause narrowing in the cross-section. In this oven a caking nut coal may be used, if necessary, without trouble. The performance of the oven is governed by ease of flow of spuelgas through the charge. Thus, the operation of the ovens with the combined heating surface/spuelgas process is less subject to the need for a certain type of coal.

DISCUSSION

Dr S. K. Sircar: In the Koppers heating surface/spuelgas process, both external and internal heating are adopted. I am interested in the rate of heat transfer through the walls. Can it be assumed that more heat is introduced by gas and steam fed at the bottom, thereby producing water gas reaction ? I presume that lump coal is used as feed to the retorts.

Dr H. H. Koppers: In the Koppers heating surface/spuelgas process for l.t.c. heat is mostly introduced from outside, i.e. through the heating walls of the ovens. The spuelgas which is fed cold at the bottom of the chamber, cools the coke and when rising, transfers again the greater part of the sensible heat absorbed from the coke, to the feed coal in the top portion of the chamber. In this way, heat recovery is achieved. A further advantage of spuelgas is that heat transfer from the heating surface to the coal is increased by additional convection thus considerably increasing the throughput capacity of the oven.

A special drying zone with separate gas recirculation is not necessary when carbonizing coal at low temperature and is only worth considering when feeding brown coal or lignite with a moisture content more than 10 per cent. The application of steam is normally not necessary. However, it is possible to use steam, if gas of certain quality is required, for formation of water gas in the chamber.

In this process, lump coal in the size range of 1/2-3 in. can be carbonized but it is preferable to use coal of 1-3 in. size so that passage of spuelgas will not be hindered.

The heat supplied through the walls of the ovens approximates to 400 kcal. per sq.m. of heating wall surface per hour.

Dr M. S. Iyengar: Dr Koppers referred to the use of silica bricks in the retort and this will increase the cost of the plant, as silica bricks are very expensive. In the pilot plant at the Central Fuel Research Institute, Jealgora, ordinary fire-bricks are used.

Dr S. K. Sircar: Semi-silica bricks have been used for the retorts probably to withstand abrasion. In India, such semi-silica bricks are not being manufactured. Silica or semi-silica bricks can be used in experimental plants but for large-scale plants, it may not be possible to use such bricks due to import restrictions. Material for construction is, therefore, very important in such plants. Have ordinary fire bricks been used and if so with what results ?

Dr H. H. Koppers: The refractory material used in the Koppers process consists of bricks containing about 70 per cent alumina. Such bricks are used in sections of the regenerators and the sections of the ovens less exposed to stress. The exterior walls of the actual oven chambers with the heating fluxes which are exposed to higher temperatures are made of silica. The quantity of bricks for these structures amount to about 70 per cent of the total quantity required. For the chamber sections, highly siliceous alumina bricks with 75-80 per cent silica and 20-25 per cent alumina have been suggested in place of pure silica.

The Production of Domestic Fuels and the Development of the National Fuels Corporation Process

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Some of the available processes for the production of smokeless domestic fuel are described. The National Fuels Corporation process is discussed in some detail. In this process, when static systems of carbonization are used the method consisting of oxidation in entrainment with air, followed by briquetting using pitch as binder is applicable to high and low volatile coals having a B.S. swelling number greater than 1. With moving system of carbonization, while low volatile coals can be processed by this method, treatment of high volatile coals requires the use of lime and tar as binder. In this case, if the swelling number of greater than 3.5 to 4, thermal or oxidative treatment is necessary to reduce it to this level.

The question of finding adequate supplies of smokeless solid fuel for domestic use concerns many countries at the present time. While the extended use of oil, gas or electricity is probably the ultimate solution, the existence of large numbers of solid fuel burning appliances, the lower cost of solid fuel generally and natural reluctance to change from the traditional open fire are at the moment causing an increased demand for reactive smokeless solid fuels.

Certain coals with low volatile matter content are practically smokeless, but usually it will be necessary to effect some degree of carbonization. The product should ideally be regular in shape, strong and reactive.

For developing new processes and for a better understanding of the underlying factors governing the results obtained, a precise knowledge of the structure of coals and the processes involved in carbonization is desirable. Much research work is being carried out in this field but our understanding of the effects observed is by no means complete and there are no laboratory tests which will establish beyond doubt the behaviour to be expected from a given coal in a full scale plant.

The present concept of the structure of coal, based on X-ray diffraction and infrared absorption studies, has been summarized by Dryden. The structure is described in terms of "cluster units" which contain from three to perhaps twenty fused hexagonal rings of carbon atoms. These aromatic nuclei are surrounded by or joined to others by short aliphatic side chains or saturated ring structures. In the low-rank high oxygen coals there are also phenolic hydroxyl groups attached to the nucleus, but this feature is not present in the coking coals. The "cluster units" are probably joined together either directly or through oxygen or short aliphatic bridges to form molecules containing probably not more than ten such units.

The mechanism of the process of fusion and caking is also not accurately known. The various hypotheses have been reviewed by Dryden and Griffith[1]. A very much simplified picture which is of help in understanding the ideas behind some of the new processes under development is as follows: On heating coal, after slight initial decomposition due to loss of constituents like carbon dioxide and water there appears a fused material. This may be present in the original coal but more probably is formed during heating. This fused material may wet the infusible residue and is itself decomposed at some stage with the evolution of gases and production of a residue of carbon. The differences between caking and non-caking coals may be regarded as being due to variations in the quantity and properties of the fusible matter formed. Thus anthracite containing little volatile matter fails to cake since insufficient fusible matter is produced. Caking coals produce more fusible material, and since the internal surface area of these coals is less, the quantity available is sufficient to bind all the infusible material. High volatile non-caking coals produce fusible material but it is readily decomposed and, in effect, disappears in such a way that there is never present sufficient to bind the remaining particles. This effect is increased by the high internal surface area of these coals. From this, one can readily understand why high rates of heating give better cokes with these coals—the fusible matter is produced, fused and binds the remaining particles all within a period of time which is too short for its decomposition.

Modifications are therefore necessary to use a non-caking coal either in the carbonizing conditions or to the coal itself. The important factors in the actual carbonization are: (*a*) Heating rates at various stages of the process, (*b*) final temperature of carbonization, (*c*) bulk density of charge, (*d*) size of particle treated (this is to some extent related to bulk density), and (*e*) mechanical stresses to which the charge is subjected.

Among available methods for varying the properties of the coal are: (*f*) Blending with other coals or other materials, (*g*) thermal pretreatment which may vary in degree up to the point where a char is produced, (*h*) oxidation, and (*i*) hydrogenation.

It will be of interest to consider the methods adopted in some of these.

Cost is an important consideration in any process and from this point of view, a simpler system is preferable. On the other hand, simpler processes will necessarily be limited in application to certain types of coals. Of the processes described below, the National Fuels process involves a greater number of steps but can treat a wide range of coals including coal of small size. For any given application, the process must be chosen keeping in view, cost, availability of coals, availability of labour, and type of product required.

THE "COALITE" PROCESS

This process has been operated for many years on a commercial scale in Britain at two works, at Askern and Bolsover.

The coals used are weakly caking smalls and carbonization is carried out in cast iron retorts each containing a nest of 12 tubes. These are 9 ft high and 4·5 in. diam. at the top increasing to 5·75 in. at the bottom. Each tube holds approximately 0·5 cwt of coal. The retorts are heated by radiation from a thin refractory surrounding wall heated on its opposite side by the combustion of coal gas.

This particular design of narrow metal chambers ensures very rapid heating of the charge so that a satisfactory product is obtained in spite of the weakly caking nature of the coal. In addition, due to the size of tube used, the size of the product is well suited to its use in domestic grates. About 90 per cent of the product is of large size and contains about 12 per cent of volatile matter and possesses reactivity which is typical of fuels produced in such low temperature systems. The tar, spirit and liquor obtained as byproducts are processed in a central refinery at Bolsover. One ton of coal yields approximately 15 cwt of low temperature coke, 16·5 gal. of tar, 3·5 gal. of spirit, 34 gal. of liquor and 4,000 cu. ft of gas with a calorific value of 700 Btu/cu. ft.

Low temperature carbonization produces greater yields of primary distillation products than high temperature carbonization and the main byproducts are motor spirit, diesel oil, fuel oils, creosote, pitch and a wide range of monohydric and dihydric phenols. Some of the phenols are processed at Bolsover to give basic materials for antiseptics and weed-killers and a non-toxic plasticizer for foodstuff wrappings.

THE "REXCO" PROCESS

The "Rexco" process was introduced before the war by the National

Carbonizing Co. Ltd., who now produce 1,50,000 tons of domestic fuel per year at Mansfield, Nottinghamshire.

The process is a batch one in which weakly caking lump coal is subjected to low temperature carbonization in retorts holding approximately 34 tons each. These retorts are cylindrical and about 10 ft in diam. and 25 ft high. Heating is effected internally by the combustion of fuel gas in the upper part of the retort, the combustion products being drawn downwards through the charge. At a certain stage the supply of fuel gas is stopped but recirculation of waste gases continues so that the carbonization is completed and the product cooled before it is discharged.

The use of internal heating ensures rapid carbonization but leads to the production of large volumes of low calorific value gas (140 Btu/cu. ft). The yields of byproducts are said to be about 18 gal. of liquid products and 25,000 cu. ft of gas per ton of coal.

Approximately 13 cwt of "Rexco" is produced per ton of coal carbonized. This is an admirable domestic fuel and the process has the great virtue of extreme simplicity.

THE C.F.R.I. PLANT

A prototype plant for the production of low temperature smokeless fuel is now in operation at the Central Fuel Research Institute. This is a modification of a process developed by the Fuel Research Station of the D.S.I.R. in Britain. The system is in some ways similar to the "Coalite" process in that externally heated narrow chambers, are used for carbonization. In this case, however, the chambers which are of firebrick are 21 ft high and 6 ft 6 in. wide; their depth is 7 in. at the top increasing to 11 in. at the bottom. Another major difference is that the operation here is continuous.

The heating system consists of 11 horizontal compartments on each side of the chamber arranged such that the gases from four burners pass downwards along these compartments to a common waste heat flue at the bottom and thence to the chimney. The flue temperatures are 1000°-1150°C. at the top and 750°-950°C. at the bottom. Provision has been made in one retort for the use of recirculation gas which should increase the throughput from its normal 20 tons/day for weakly caking coal to 30 tons/day.

It is to be expected that a unit of this type will give products both coke and byproducts similar to those from the "Coalite" plants.

NATIONAL FUELS PROCESS

The National Fuels process utilizes two methods of varying the properties of the coal, namely, addition of a binding material and oxidation. For the actual carbonization the effective density of the charge is increased

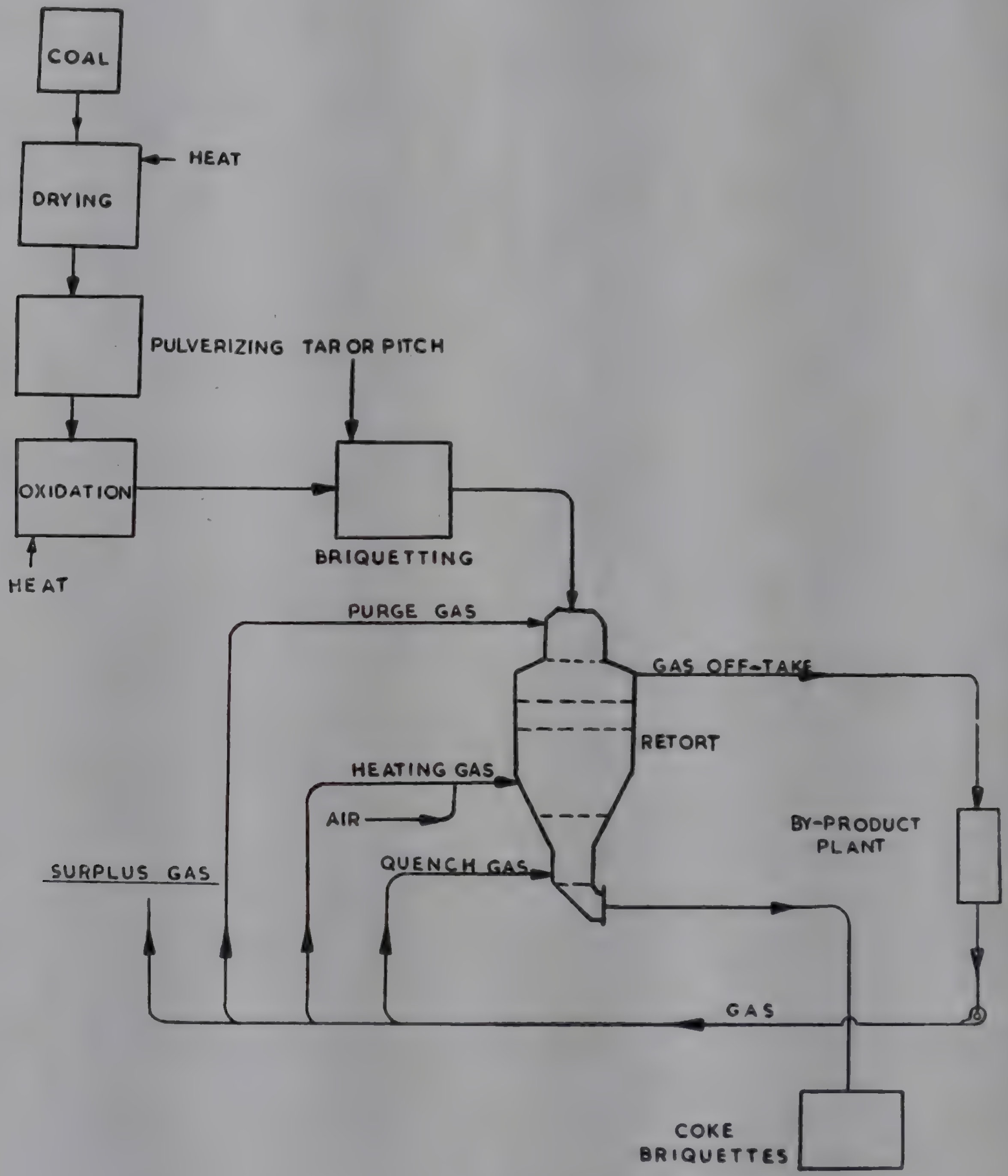
COAL
HEAT
DRYING
PULVERIZING
TAR OR PITCH
OXIDATION
HEAT
BRIQUETTING
PURGE GAS
GAS OFF-TAKE
RETORT
HEATING GAS
AIR
BY-PRODUCT PLANT
SURPLUS GAS
QUENCH GAS
GAS
COKE BRIQUETTES

Fig. 1—Flowsheet of National Fuels Corporation process

by briquetting, which also results in a uniform product with regard to size and shape. Other factors are carefully controlled.

The process was developed originally by the National Fuels Corporation of New York and the American Cyanamid Company. Two pilot plants were built, one on a semi-laboratory scale at New Haven and the other, with a capacity of 100 tons/day, at Bethlehem, Pa.

More recently, Simon-Carves Ltd., who are licensees for the process, working in conjunction with the North-Western Gas Board, built a pilot plant of 1 ton/hr capacity at Bollington in Chesire. The complete National

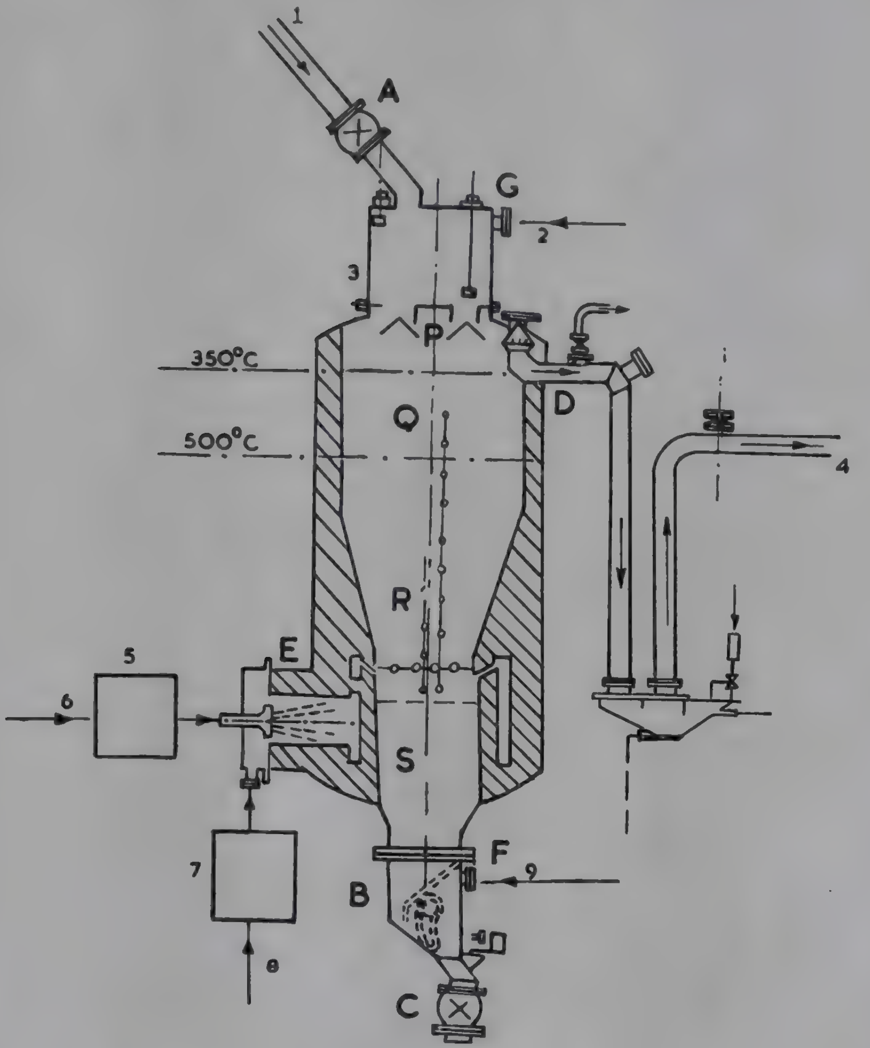

FIG. 2—NATIONAL FUELS CORPORATION RETORT: (1) Briquette feed (2) Purge gas (3) Feed bin (4) Gas to byproduct plant (5) Preheater (6) Tuyere gas (7) Preheater (8) Air (9) Quench gas

Fuels Corporation process uses a specially designed retort for carbonizing the briquettes, but work at Bollington was directed towards the production of a reactive domestic fuel in existing retorts mostly continuous vertical chambers. The Rochdale process of recycling gas through such retorts to increase the rate of heating had already been developed by the Gas Board and it was hoped to utilize this system.

During the course of the work at Bollington a variation in the process was introduced but the essential steps of the original process were: (*a*) Drying of the coal to a moisture content of less than 1 per cent, (*b*) pulverization of the coal, (*c*) oxidation to reduce the coking properties to a predetermined level, (*d*) briquetting with a pitch binder, (*e*) carbonization of the briquettes.

A flow diagram of the process is shown in Fig. 1. Coal is fed from storage to primary crushers from which it passes to blending bunkers (if required) and then to attritors. These are swept with a stream of hot gases produced by the combustion of part of the gas made in the plant or by combustion of coke. The attritors serve to crush the coal to the required size (at least 90 per cent should pass through 28 mesh Tyler screen) and to dry the coal to a moisture content of 1 per cent.

After separation from the hot gas stream, the fine coal is entrained in an air stream which is fed through a heated coil in the oxidizer and immediately cooled. The coal is removed from the air stream by means of cyclones and fed to the briquetting section of the plant where it is mixed with pitch or tar binder and the correct amount of moisture, and briquetted. The briquettes are passed along a cooling conveyor to harden them and over a screen to remove any fine material before being charged to the retort.

The National Fuels Corporation (N.F.C.) retort is shown in Fig. 2. The structure comprises a steel shell approximately 8 ft in diam. and 20 ft high lined with refractory material. A rotary vane air lock at the top allows the introduction of the raw briquettes into a feed bin on top of the retort. This is flushed continuously with a stream of purge gas returned from the byproduct plant. From the feed bin the briquettes are fed through four cylindrical splitters to give an even distribution of the briquettes in the retort. The briquettes then pass downwards, being heated by hot gases rising through the retort, until they reach the cooling section where they are cooled by a stream of cold gas, also recycled from the byproduct plant before removal from the retort.

Heating of the retort is achieved by burning preheated recycled gas in a bustle with preheated air and introducing the hot waste gases immediately into the retort. The use of preheated air enables gas of a calorific value approximately 480 Btu/cu. ft to be made. The gases then rise upwards with the cooling gas introduced in the lower part of the retort. As the gases rise, gas produced from the briquettes is also admixed, and the gases leave the retort at a temperature of approximately 150°C. The briquettes are heated to about 900°C. or any other temperature depending upon the required volatile matter content of the carbonized product, before being cooled.

The byproduct plant is very similar in general layout to an ordinary coke oven or gasworks byproduct plant except that there is no light oil to be recovered. Little benzol or naphthalene is produced, the byproducts being mainly primary tars and ammonia.

BOLLINGTON PILOT PLANT

Apart from the use of modified existing retorts the pilot plant at Bollington (Fig. 3) provided complete facilities for development of the process just outlined.

Coal of size substantially smaller than 0·5 in. was fed by means of a

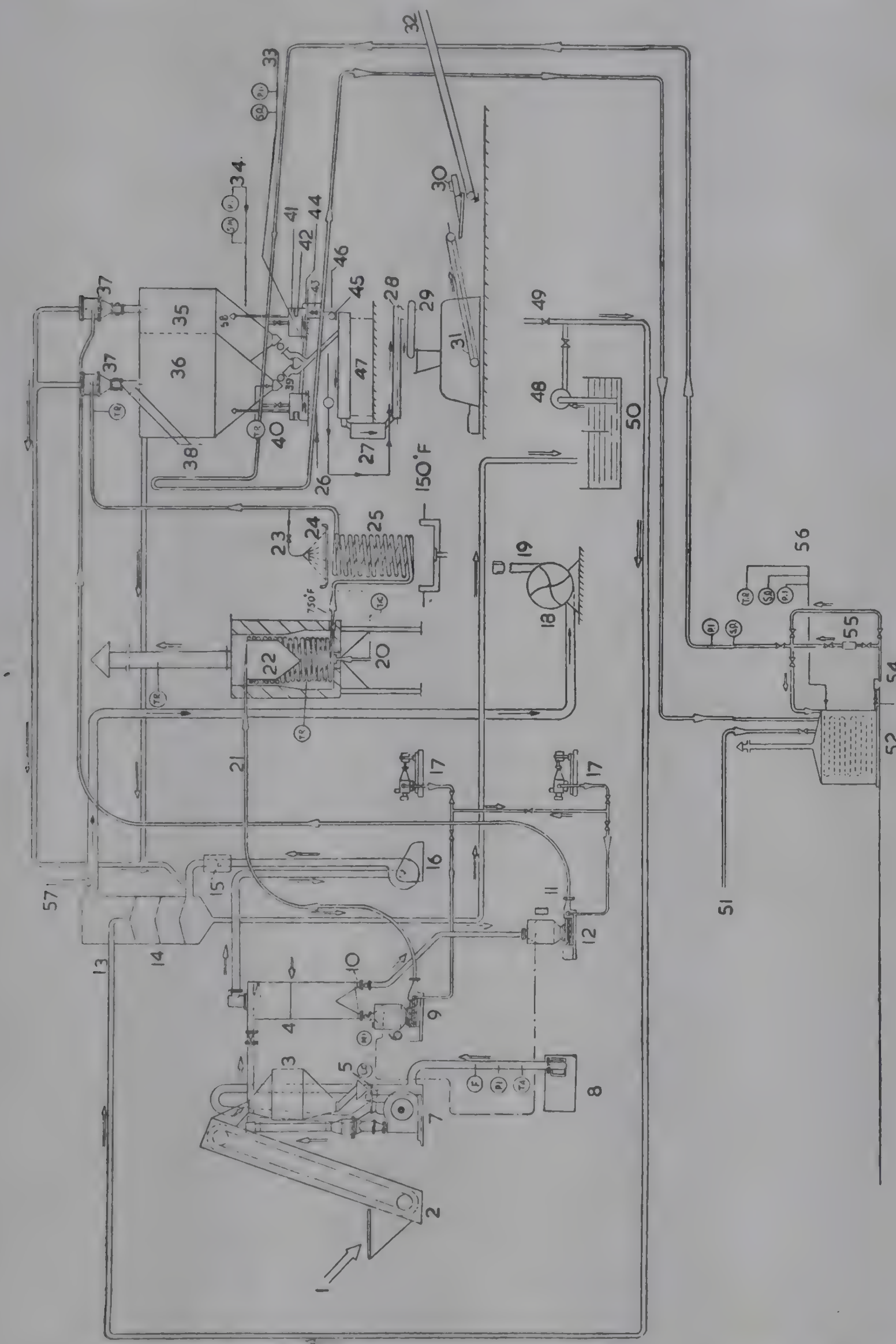

FIG. 3—FLOWSHEET OF PILOT PLANT: (1) Coal (24 tons/day) (2) Coal elevator (3) Attritor feed hopper (4) Cyclone (5) Table feeder (6) Feed hopper (7) Attritor (8) Furnace (0.5 tons coke/day) (9) Fuller Kinyon pump (1500 cu. ft/min.) (10) F. K. rotary feeders (11) Feed hopper (12) Fuller Kinyon coal pump (13) Spray water (14) Schneible washer (15) Butterfly valve silencer (16) Circulating fan (17) Compressor (90 cu. ft/min. minimum) (18) Washer fan (19) To atmosphere (20) Gas (1500 cu. ft/hr) (21) Coal ratio—5.45/1, Velocity—1367 ft/min. (22) Oxidizer (23) Water (300 gal./hr) (24) Trough (25) Oxidizer cooler (26) Water feed (27) Fluxer (28) Conveyor screw (29) Conveyor (belt) (30) Vibrating feeder (31) Briquetting press (32) Coal briquette conveyor (air-cooled, mesh belting) (33) Steam (80 lb./hr maximum) (34) Steam (35) Raw coal hopper (36) Oxidized coal hopper (37) Cyclone (38) Coal discard (39) Motorized valve (40) Feeder (41) Pitch tanks (42) Immersion heater (43) Drain (44) Overflow (45) Pitch metering pump (46) Steam/pitch injectors (47) Differential mixer (48) Water circulating pump (49) Fresh water (50) Settling tank (51) Liquid pitch (52) Pitch melting vessel (53) Condensate (54) Pitch pump (55) Pitch filter (56) Steam (400 lb./hr maximum) (M.I.) Moisture indicator (M.C.) Moisture control (T.A.) Temperature alarm (F) Flowmeter (T.R.) Temperature recorder (T.C.) Temperature controller (L.C.) Level controller (S.M.) Steam meter (W.M.) Water meter (S.O.) Steam orifice plate (P.I.) Pressure indicator

bucket elevator to a raw coal hopper and thence moved by gravity on to a rotary feed table and into the attritor. This was an Alfred Herbert No. 8 model designed to handle 1 ton/hr and to give a product of size 95 per cent passing through 25 B.S. sieve with less than 1 per cent moisture. The attritor was swept by hot gases from a coke furnace, which were drawn through the system by an induced draught fan. The crushed dry coal was carried out of the attritor by these gases and separated out in a cyclone from which it fell into the feed bin of one of two Fuller-Kinyon pumps. These pumps consist essentially of a helical screw driven by an electric motor which propels the coal through a non-return flap into an exit chamber where the coal is entrained in a stream of air from compressors.

The coal/air stream from one of the pumps passed through the oxidizer and cooler, and the coal was then removed from the air stream in a cyclone for storage in an oxidized coal hopper. From the second Fuller-Kinyon pump the coal was passed into a hopper for unoxidized coal by a similar system but with no oxidizer or cooler. The oxidizer consisted of a coil of stainless steel tubing, suspended in a mild steel cylinder which was lined with insulating refractory material. Waste gases from a ring gas burner were led past the coil and then to atmosphere via a small stack. The oxidizer was connected by a short length of tubing to the cooler which consisted of a coil of the same stainless steel cooled by water sprays.

From the oxidized or unoxidized coal storage hoppers the coal could be fed via rotary valves to the mixing system. Various mixers were tried but finally twin shaft differential continuous mixers followed by a vertical pug mixer were adopted. The binder of low melting point pitch was distributed over the coal by means of steam injectors and provision was made for the addition of water and further steam heating at a number of points.

The pitch/coal mixture was fed to a roll press. This was operated at a throughput of 2 tons/hr. It was of heavy construction having a frame of welded and rivetted steel sections with heavy bearings carrying the rolls and driving gear wheels. The rolls were driven through reduction gears by a reversible motor and the roll speed could be varied from 1 to 4·75 r.p.m. Each roll was 25 in. in diam. with cups machined into its surface for the formation of the briquettes. Various briquette shapes were tried but the briquettes had usually a volume of approximately 38 ml.

Raw briquettes leaving the press were passed by means of a vibrating feeder, which was arranged to remove fine material, to the cooling conveyor. This was a stainless steel mesh belt 2 ft wide and 50 ft long which cooled the briquettes and elevated them into the storage bunker.

As mentioned previously, the special N.F.C. retort was not used in connection with the work at Bollington, a variety of existing carbonizing equipment being used. These included horizontal, intermittent vertical and continuous vertical retorts, the Rochdale system of recycling gas through the retort being used with the latter.

RESULTS AND DISCUSSION

The object of the process is to produce strong carbonized briquettes from a wide variety of coals, and it will be of interest to consider the objects of each stage of the process and the extent to which these are achieved.

The main functions of the binder are to hold together the coal particles so that the raw briquette can be handled, and to give the briquette sufficient strength to withstand the headload in the retort until the outer layers at least have been carbonized to give a strong "shell". Although there will be some residue from the pitch this cannot be counted upon to give the necessary strength to the final product and it is desirable that the coal should have some degree of caking power. On the other hand, a coal which swells appreciably would obviously give rise to badly swollen and fissured carbonized briquettes unless its swelling characteristics are modified. The purpose of the oxidizer is to suitably modify the swelling characteristics of the coal so that in the crucible swelling test it gives a strong unswollen button, and has a B. S. swelling number of 1 to 1·5.

The N.F.C. oxidizer was found to be well suited for this purpose. The coal and air stream were raised to temperatures of 250°-400°C. depending upon the coal being treated. Although these temperatures were, in many cases, within the range where the coal is plastic, no agglomeration occurred even with loadings as high as 15 lb. of coal per lb. of air.

The retention time in the oxidizer was 2-4 sec. Volatile matter lost during oxidation amounted to less than 1 per cent and consisted mainly of water and carbon dioxide. Rapid cooling of the coal was, of course, necessary to give accurate control over the degree of oxidation.

It is very important that the grinding of coal should be such that the particle sizes will have as narrow a range as possible. The oxidation of the coal is primarily a surface reaction which is carried out at a fixed temperature for a fixed time and is not carried to completion. Consequently, any large particles present are relatively less oxidized than small ones and in subsequent carbonization cause localized swelling in the briquette. With coal particles of size up to 1/16 in. it was, for example, found that when the coal as a whole was oxidized so that its swelling number was reduced to 1, the coal of size less than 240 mesh had no residual agglutinating power whatever.

Pulverization also results in a thorough blending of the banded constituents of the coal again leading to more uniform agglutination within the briquette.

The drying of the coal to a moisture content of 1 per cent was necessary as the presence of excess water vapour in the air used for oxidation would tend to decrease the speed of the oxidation reaction. In addition the resulting rise in the dew point of the air with increased moisture gave rise to

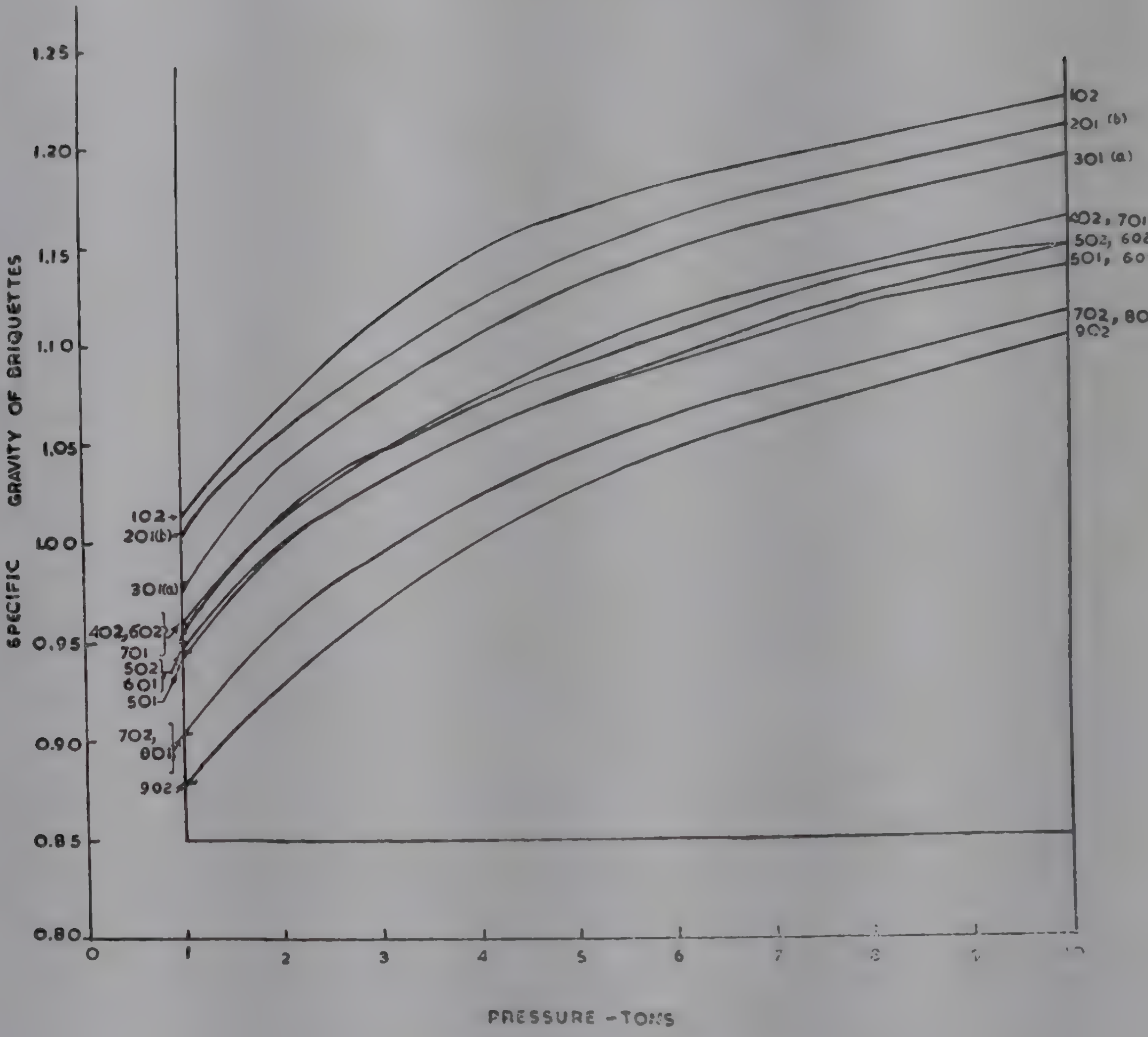

Fig. 4—Specific gravity of briquettes

condensation in the cooling coil and cyclone causing operating troubles due to blockages and corrosion.

Experiments were carried out in various types of retorts for carbonization. No difficulties were experienced when carbonizing in static bed systems such as horizontal retorts or a 10 cwt test coke oven. Difficulties did, however, arise in using moving heating systems, i.e. in continuous vertical retorts. In these, it was found that briquettes from coals with less than about 23 per cent of volatile matter could be successfully carbonized but those from high volatile coals (30 per cent) gave low yields of whole briquettes, most of the product appearing as small pieces or breeze.

The reason for this is not clear but one factor of obvious importance which was investigated was the density to which the coal could be compacted in the briquette. It was soon realized that briquettes from the high volatile coals were less dense than those from low volatile coals. In further investigations, small samples of various coals ground to a similar size grading were compressed in a suitable die, and the length of the pellet formed at different pressures was measured. It was thus possible to plot curves of density against

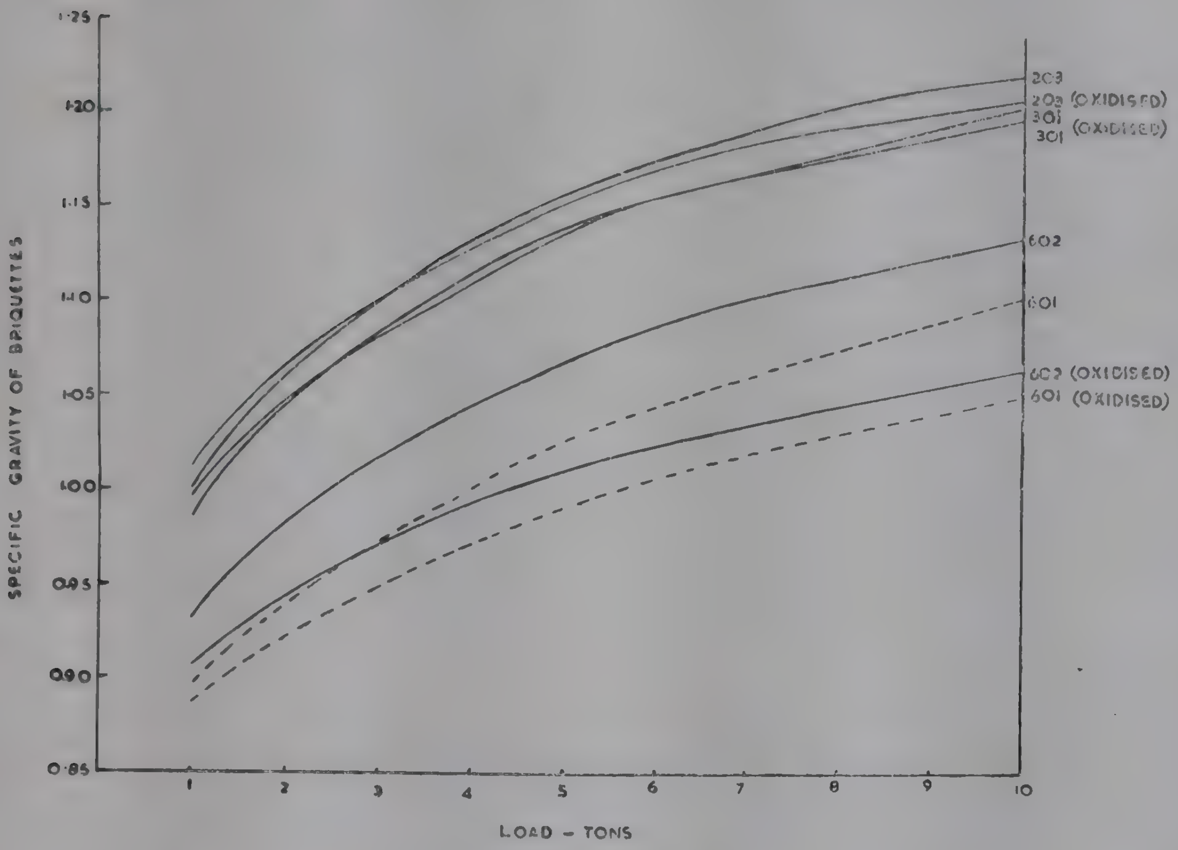

FIG. 5—EFFECT OF OXIDATION ON SPECIFIC GRAVITY OF BRIQUETTES

pressure. Fig. 4 shows typical curves for a number of coals identified by their N.C.B. classification. Although exceptions do occur, it will be seen that, in general, coals with higher volatile matter content pack to lower densities than those with low volatile matter. These differences were accentuated by oxidation which was found to have little effect on the density of a pellet from a low volatile coal but to reduce the density of one from a high volatile coal markedly, as shown in Fig. 5. The effect is perhaps understandable when it is recalled that during oxidation coal particles are heated. Experiments showed that the higher the temperature at which oxidation was carried out the lower the pellet density. Oxidation was also accompanied by an increase of internal surface area. Some degree of sintering of the particles is thus apparent. A number of causes for the effects just described are possible. From the point of view of density of raw briquettes, grinding to give a wide range of particle sizes would be an advantage but the requirements mentioned previously of the oxidation system militate against this. The results could be explained in terms of the different shape of particles produced when different coals are ground to similar sizes and the effect of oxidation on the shape of the particles. This effect may be of minor importance, examinations under the microscope having shown that the differences in shape are not great. An alternative explanation was that the effects were due to variations in the wettability of the coal surface.

A much more probable explanation lies in the porosity of the coal particles. As is well known the best coking coals (Type 301) have the minimum internal porosity and these gave the best compaction, other coals becoming progressively worse as the porosity increased. The results of inherent moisture determinations, which are related to porosity, also followed the trend of the densities obtained.

Since many related properties follow the same pattern as internal porosity, this evidence does not necessarily indicate that porosity itself is the cause of the effects observed, but it is the most probable cause and the results do indicate the coals suitable for use in the original N.F.C. process.

Whatever the actual cause, the importance of the low density of the briquettes from high volatile coals is clear. The lower actual area of contact between particle to particle results in less firm bonding. This is all the more serious since it occurs with coals which often require higher oxidation temperatures causing a greater reduction in particle density and which, on carbonization, leave a smaller quantity of carbon residue so that the briquette becomes still less dense and less strong.

The solution to the difficulty was found in the use of a different binding material. It was observed that the use of tar as a binder enabled carbonized briquettes to be produced without any tendency to swell from coal of swelling number 3 or 4. Thus the degree of oxidation required with coals of higher swelling number was reduced while coals of swelling number 4 or less required no treatment in the oxidizer. The quantity of tar required to produce this effect varied with the coal used but in many cases was such that the briquette would collapse during initial heating. It was, however, known that the addition of lime to tars causes a polymerization which increases the stability of the tar on heating and the effect on the coal swelling characteristics was found to be greater in the presence of lime. Consequently, by using a binder of tar, lime and pitch it was possible to treat coals with swelling numbers up to 4 without oxidation. Coals of higher swelling number could be oxidized to reduce their swelling number to 4 and with this new binder still gave a briquette which could be carbonized as a moving burden.

Investigations were made to identify, if possible, the actual constituents of the coal responsible for the effects observed. It was known that the polymerizing effect of lime arose from reactions with tar acids and it was shown that the effect of different distillation fractions of the tar on the coal swelling number was greater for those fractions containing maximum tar acids. In general, the effect was enhanced by additions of lime.

Experiments carried out with *o*-cresol, 3,4-xylenol and pyrogallol with and without addition of lime showed that the greatest lowering of swelling number in the absence of lime was given by pyrogallol but the greatest difference resulted from the use of *o*-cresol with lime.

THE PRODUCT

The carbonized briquettes produced by the N.F.C. process provide a smokeless fuel of uniform size and free from dust. Those made at Bollington usually contained about 8 per cent volatile matter and only 2·5 per cent ash since the coal in use had a particularly low ash content. They were excellent for use on open coke grates or closed appliances. If increased reactivity was desired, this could be achieved by leaving a greater residue of volatile matter in the product although the briquettes made were surprisingly reactive, perhaps due to the increase in surface area caused by oxidation.

To assess the strength of the briquettes a modified form of Shatter Test was used in which whole briquettes were subjected to the usual 6-ft drop four times, the percentage remaining whole being recorded. The briquettes usually yielded about 90 per cent whole briquettes and only 5 per cent less than 0·5 in size.

As a result of the work described the National Fuels process has now been more fully developed for use with a wide range of coals, the carbonization being carried out in static or moving burden systems.

The processes just discussed are by no means the only systems available for producing the smokeless domestic fuel so urgently needed in India and other countries. They do, however, illustrate in general the types of process available and their field of application. As mentioned previously, the choice of process depends on local conditions and experimental work will be necessary to assess the suitability of a given process in a given case. It is important that this work should be vigorously pursued.

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Prototype Low Temperature Carbonization Plant at the C.F.R.I. and the Results of Some Preliminary Trials

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The main features of the prototype low temperature carbonization plant installed at the Central Fuel Research Institute, consisting of two narrow continuous vertical retorts each of 10 tons/day capacity are described. The carbonization is carried out at a temperature of 600°-700°C. The throughput rate can be increased by a gas injection system. Results of preliminary trials with coals from Bihar and West Bengal coalfields are presented.

Low temperature carbonization (l.t.c.) of coals and briquetting of coal fines as a multipurpose integrated project for production of domestic coke in different coal-bearing areas and near large cities, and as a new sector of industrial development in the country has been emphasized recently[1,2]. Apart from the l.t.c. plant for processing of lignite briquettes (1200 tons coke/day capacity), two more plants of similar or higher capacity are expected to be established in the public sector in the Bihar and Bengal coalfields to process sized coal. Lately, the private sector has also shown keen interest in installation of large-scale plants in Madhya Pradesh, Maharashtra, West Bengal and Bihar States.

Extensive data have been collected on the l.t.c. characteristics at the Central Fuel Research Institute, both on laboratory and semi-pilot plant scales of different coals which have shown that most of the coals from Assam, Raniganj and Madhya Pradesh and some from Bokaro-Ramgarh-Karanpura areas are suitable for l.t.c. But before establishing a commercial plant, an accurate knowledge of the quantity and quality of the products is essential, and therefore the Institute suggested, as early as 1950, the installation of a full-scale l.t.c. plant complete with byproducts recovery unit for large scale tests on Indian coals. This plant would supply not only technical data on l.t.c. characteristics of various Indian coals but also other pertinent process data for preparation of project reports (Fig. 1).

After considering the two main types of l.t.c. processes that are available (internally heated and externally heated), the variety of coals likely to be treated, and the fact that an internally heated type pilot plant has been in operation at Hyderabad, it was decided to instal an externally heated-type plant.

The plant is, in a way, a modification of the process developed by the Fuel Research Station, U.K. Its erection began in 1957 and was completed during 1960. The various units of the plant and certain special features are described below:

COAL HANDLING ARRANGEMENT

Coal is unloaded into six underground bunkers, each of 50 tons capacity, from where it is conveyed to a 3 in. screen via a magnetic separator for removing iron pieces. Very large pieces of coal (about 8 in. size) are manually broken. The +3 in. coal is crushed to —3 in. size and screened at 1 in. and the 1—3 in. size is then filled into tubs of 18 cu. ft capacity by a belt conveyor. The —1 in. slack (with lower ash content) is used for steam generation, for blending in nearby high temperature carbonization pilot plant and for briquetting and the surplus is sold outside. The coal tubs are weighed and then unloaded into a 6 cwt skip, which is then electrically hoisted to the top of the oven block.

RETORTS AND THE HEATING SYSTEM

The oven block consists of two downward heated continuous type narrow firebrick vertical retorts of the following dimensions: height 21 ft, major axis 6 ft 6 in., and width 7 in. at the top increasing to 11 in. at the bottom. These have been built independent of each other by providing a wall between them to enable easy operation of the two retorts under two different sets of operating conditions and also shuting down of one retort for repair without affecting the other. Each retort is heated externally by eight special type gas burners, four on either side of the retorts placed one below the other in alternate passes. The capacities of the burners (number of burners used in each of the rows is four) are as below:

(*i*) Top row—No. 1 pass, capacity of each burner 1050 cu. ft/hr at 4 in. W.G.

(*ii*) 2nd row—No. 3 pass, capacity of each burner 650 cu. ft/hr at 4 in. W. G.
(*iii*) 3rd row—No. 5 pass, do 350 do
(*iv*) 4th row—No. 7 pass, do 350 do

Air required for combustion is supplied by means of an air fan of 1650 cu. ft/min. capacity at a pressure of 7 in. w.g. A stand-by is also available.

The combustion chambers (flues) on both sides of the retorts have been divided into 11 compartments (each about 18 in. deep and 4·5 in. wide called "flue passes") by means of horizontal walls arranged in such a way that the products of combustion travel downwards from the top in a zig zag horizontal path to a common waste heat flue at the bottom and then pass out through a 16 in. diam. and 55 ft high chimney provided with individual dampers to have controlled suction in each flue. The draught in the chimney is controlled by varying the pressure of steam at the jet provided at the top. This method of heating gives a uniform gradation of temperature in different sections of the retorts.

The type of coal to be charged, its size, its coking properties and the desired coal throughput determine the temperatures to be maintained in the flues. The temperatures in the flue passes are controlled by adjusting the heat input. For studying the sized coals at different throughputs, the following typical temperature ranges have been maintained in the flue passes No. 1, 2, 3, 5, 7 and 9: 1050°-1100°C.; 980°-1000°C.; 950°-1000°C.; 900°-950°C.; 850°-900°C.; 700°-750°C. respectively. The temperature of the inside surface of the retort walls is likely to be between 600 and 700°C.

The retorts are heated by the rich l.t.c. gas produced during carbonization. They can also be heated by normal coke-oven gas or lean gas. Fuel gas for heating is supplied to the burners from a gas holder through a 6 in. main. Fig. 2 shows the burner pipe.

CARBONIZING TECHNIQUE

Coal is dropped into two separate receiving hoppers (each of 8·6 cu. ft capacity) (Fig. 3). Coal is then charged into two separate "coal boxes" (auxiliary intermediate hoppers, each with a capacity of about 12 cu. ft) by opening the coal valves. Coal on entering the retorts receives a thermal shock due to the high temperature maintained at the top flues. Due to high temperature gradient the penetration of heat to the charge is quite rapid. The rapid heating of coal at the upper and middle flues enables carbonization at higher coal throughput. When the charge descends and finally reaches the bottom of the retorts, carbonization is complete.

Each retort is provided with a separate coke chamber and a coke discharge mechanism. Coke is quenched inside the chamber itself by passing steam continuously. Normally the steaming rate is sufficient to bring down the temperature of coke below its ignition point, but if necessary in very

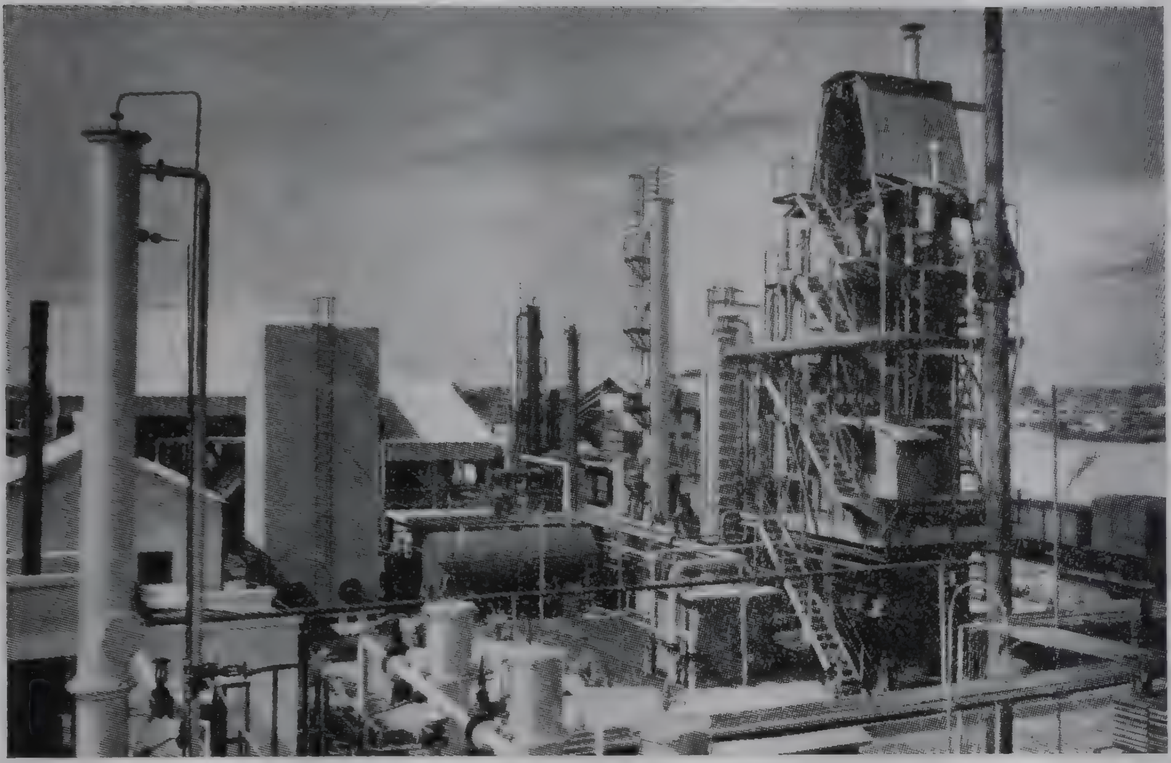

FIG. 1—L. T. C. PLANT AT CENTRAL FUEL RESEARCH INSTITUTE

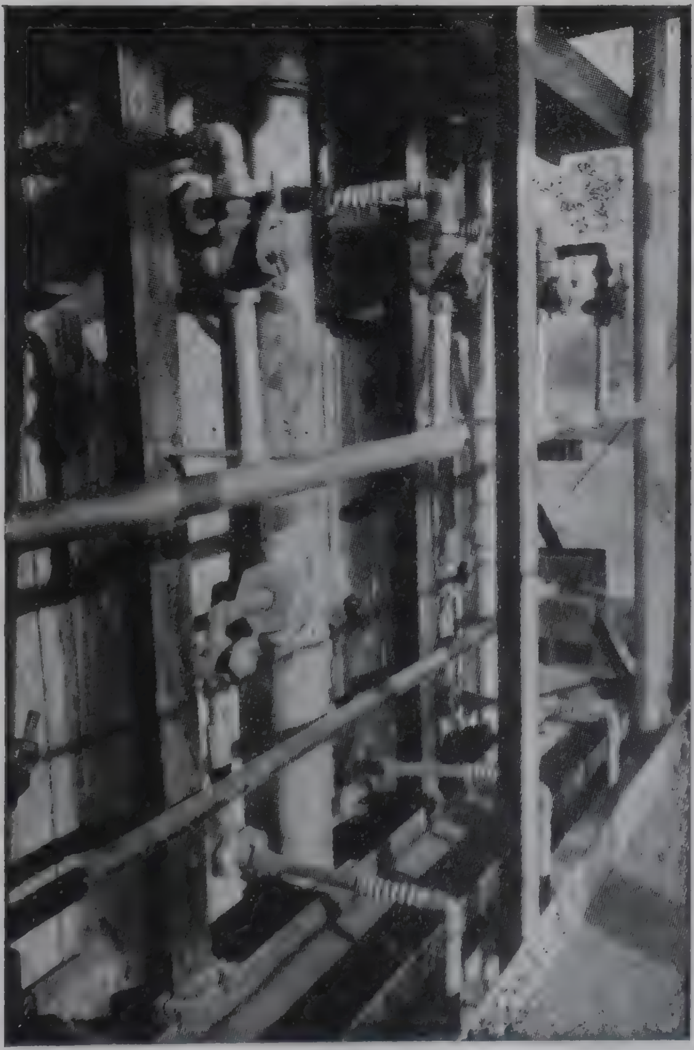

FIG. 2—BURNERS OF THE L. T. C. PLANT

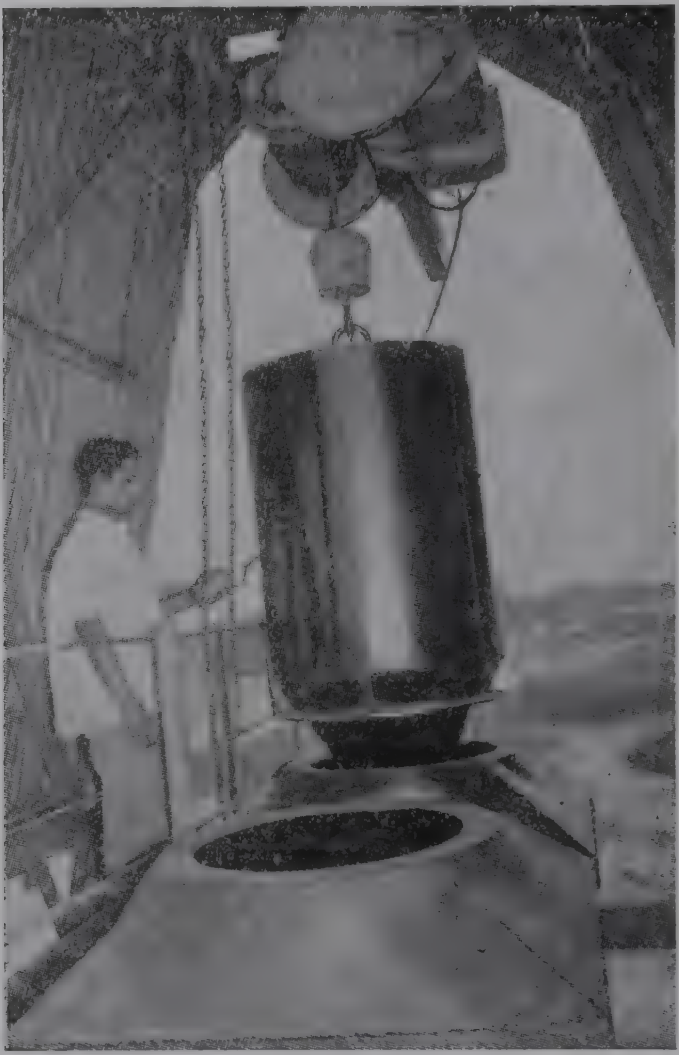

FIG. 3—COAL CHARGING HOPPER

hot season, coke can be further cooled by a mild water spray after discharge. The steaming rate determines the heating value of the make gas. Coke collected in the chambers is periodically discharged into 18 cu. ft capacity trolleys (Fig. 4) which are, after weighing, taken to a coke storage. Thus coal is continuously fed into the retorts at the top and steam-quenched coke is continuously discharged at the bottom without emptying the retorts and interrupting the carbonization process.

COKE EXTRACTION

Coke is extracted from the base of the retorts by means of a "tooth and comb type coke extractor". The coke is supported by means of mild steel combs and cast iron hanging bars which form parts of the extractor. The combs bent at an angle of 90° are fitted to the coke chambers by means of bolts and nuts. The hanging bars are fixed at the opposite side of the coke

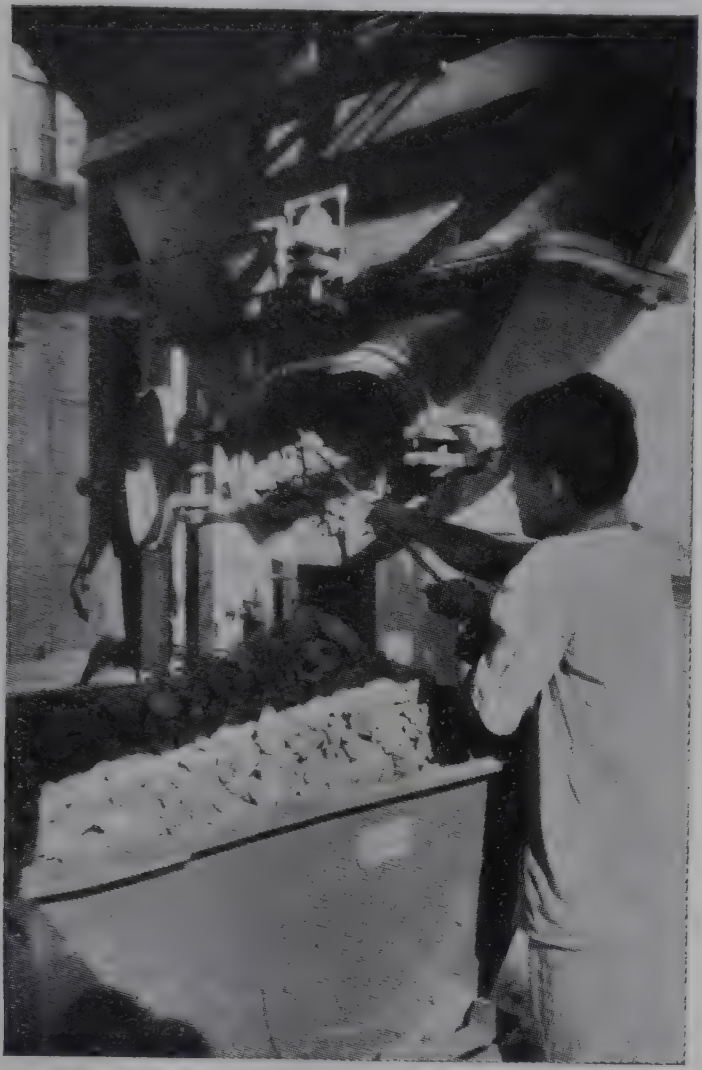

FIG. 4—COKE DISCHARGE

chamber. The tips of the combs are in contact with the freely hanging bar ends and these together carry the entire weight of the charge.

The extractor teeth (every alternate one fixed at an angle of 90°) fitted to a square shaft, which passes through gas-tight glands in the outer removal end plates of the coke chamber, are placed just below the combs. The shaft is mechanically rotated when the teeth pass through the free space between the combs, pushing coke forward to the hanging bars, which move backward, thereby creating open space between the tips of combs and the ends of hanging bars, through which coke pieces fall into the chamber below. Arrangements are provided to alter the r.p.m. of the coke extractor shaft within limits, so that the rate of coke extraction can be varied. The rate of coal throughput is adjusted by the rate of coke extraction.

THE BYPRODUCTS UNIT

The volatile products of carbonization leave the retorts and pass through the offtake pipes located at the major axis ends of each retort. The products

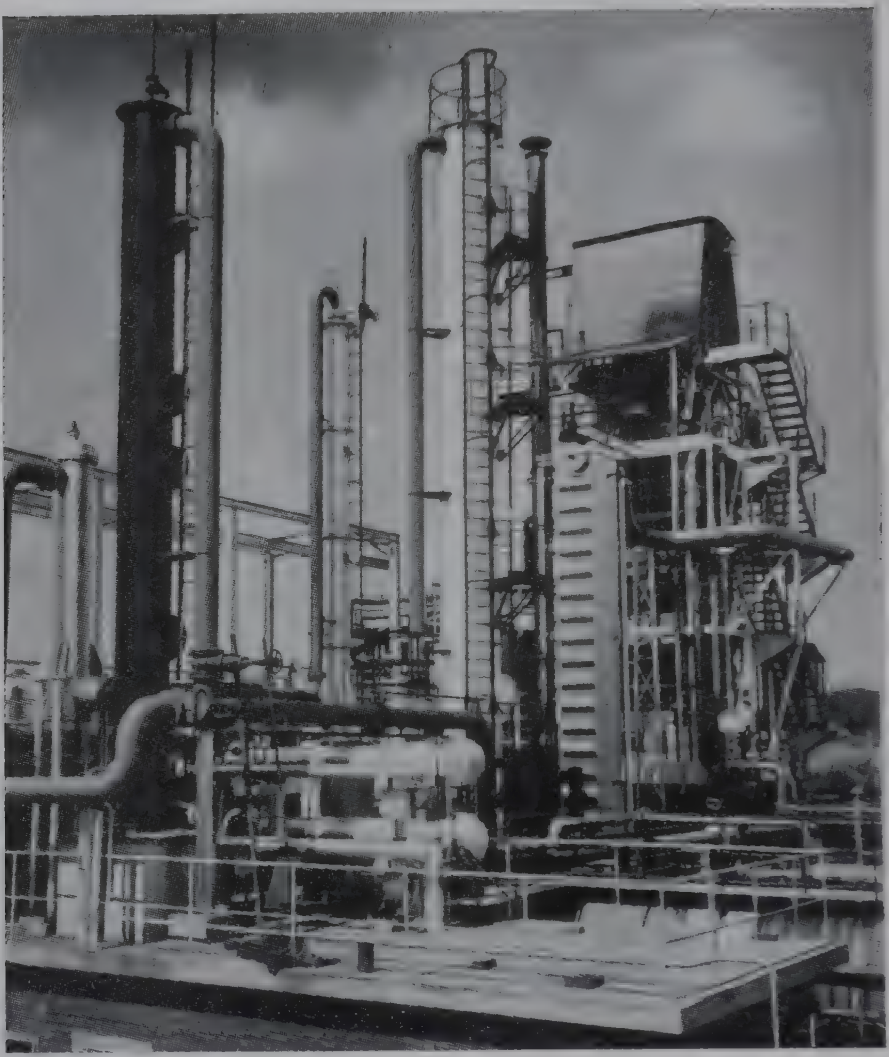

FIG. 5—BYPRODUCTS RECOVERY UNIT

enter a common hydraulic main, where they are cooled by liquor spray. There is provision to isolate the idle retort from the hydraulic main whenever necessary. Provision is also made to vent the gaseous products directly into atmosphere if necessary, or in event of exhauster or power failure. The products then go through a retort house governor, which maintains the retorts under a slight pressure (Fig. 7). A stand-by governor is also available. A major portion of the tar (particularly the heavier fraction) and liquor condense in the hydraulic main. From the governor the gases containing remaining liquor and lighter tar fraction go through a foul gas main to a primary cooler, where tar and liquor are separated further from gases. The cooled gases then pass through an electrostatic tar precipitator for removal of finer tar particles and mist from gases. Next in line are gas exhausters which suck the gases through the units and delivers them to a final cooler, which takes away the heat generated as a result of compression. The cooled gases then pass through an ammonia washer where most of the ammonia is scrubbed by means of cold water. The ammonia-free gas then

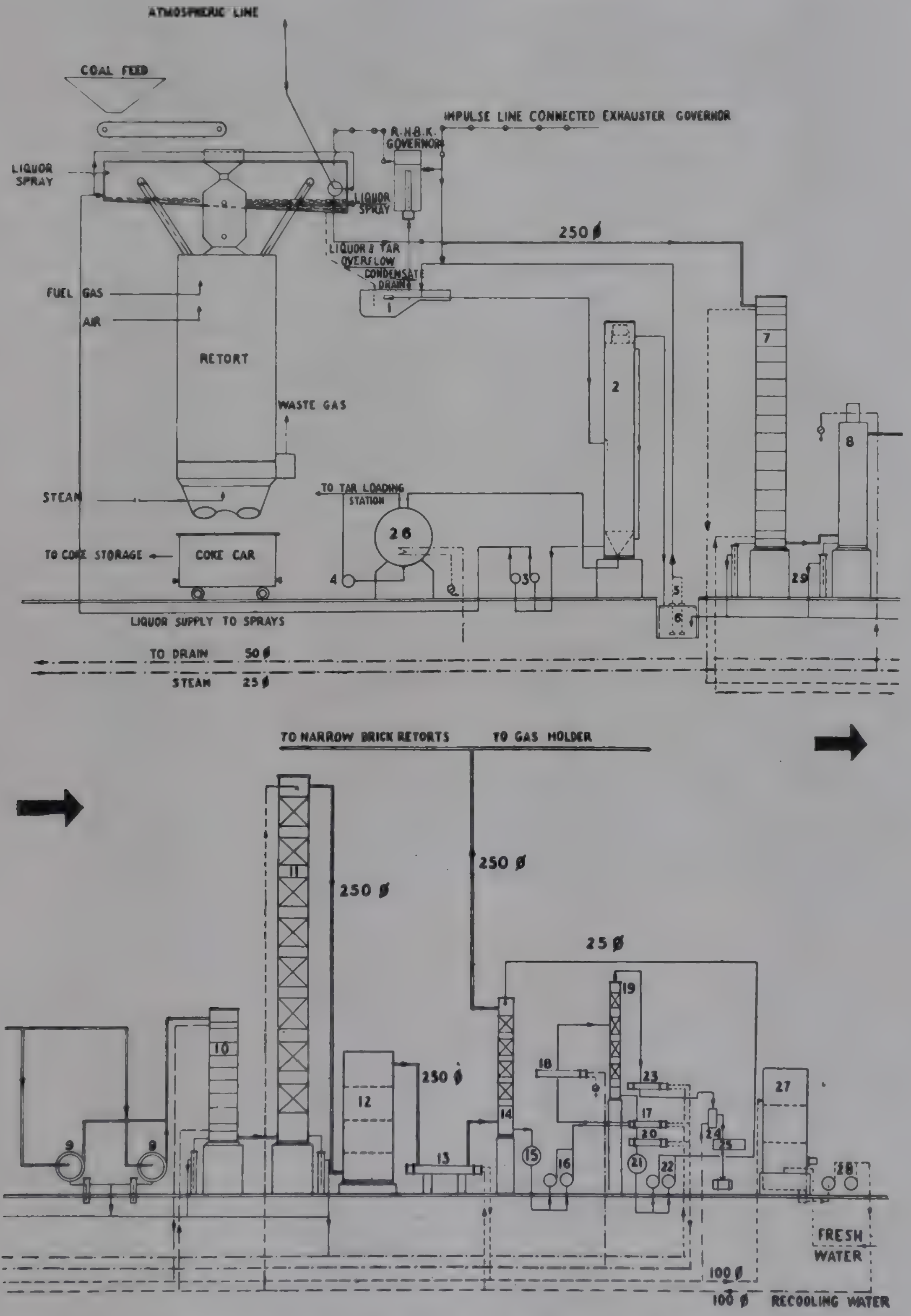
ATMOSPHERIC LINE
COAL FEED
IMPULSE LINE CONNECTED EXHAUSTER GOVERNOR
R.H.B.K. GOVERNOR
LIQUOR SPRAY
LIQUOR SPRAY
250 ø
LIQUOR & TAR OVERFLOW
CONDENSATE DRAINS
1
FUEL GAS
AIR
RETORT
2
7
WASTE GAS
8
STEAM
TO TAR LOADING STATION
26
TO COKE STORAGE
COKE CAR
4
3
5
6
29
LIQUOR SUPPLY TO SPRAYS
TO DRAIN 50 ø
STEAM 25 ø
TO NARROW BRICK RETORTS
TO GAS HOLDER
11
250 ø
250 ø
25 ø
19
10
18
23
12
250 ø
27
17
20
24
25
9
9
14
13
15
16
21
22
28
FRESH WATER
100 ø
100 ø RECOOLING WATER

Fig. 6—Flowsheet of L. T. C. Plant: (1) Thick tar container (2) Separator tank (3) Pumps for spraying liquor (4) Pump for tar loading (5) Submerged pumps (6) Condensate box (7) Primary cooler (8) Electric tar separator (9) Exhauster (10) Final cooler (11) Ammonia washer (12) Sulphuretted hydrogen dry purification plant (13) Gas cooler (14) Benzol absorption column (15) Wash oil collecting tank benzolized oil (16) Benzolized oil pumps (17) Heat exchanger (18) Oil heater (19) Stripping column (20) Wash oil cooler (21) Wash oil collecting tank (debenzolized oil) (22) Debenzolized oil pumps (23) Vapour cooler (24) Separator tank (separating benzol and water) (25) Benzol storage tank (26) Tar storage container (27) Forced draft cooling tower (28) Cold water circulating pumps (29) Tar drip pot

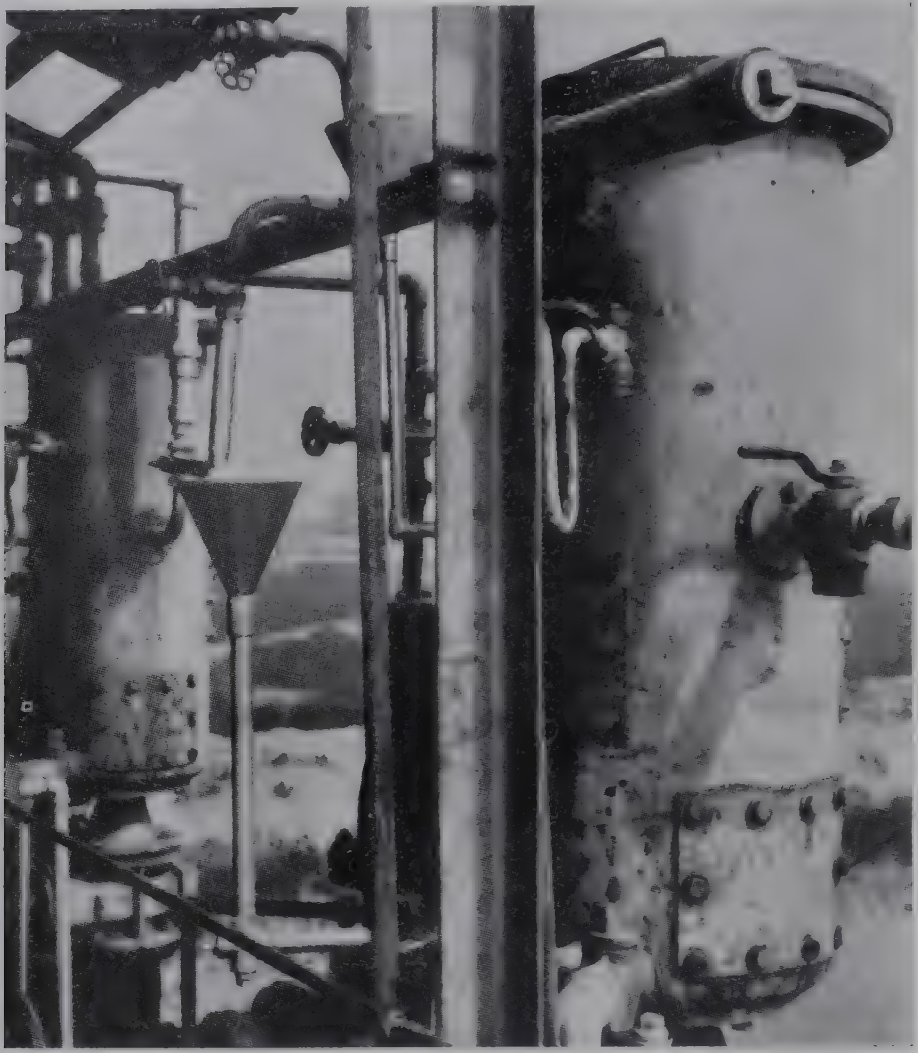

FIG. 7—RETORT HOUSE GOVERNOR

enters purifier house where hydrogen sulphide is separated from the gases. The gas, thus freed from tar, ammoniacal and phenolic liquor and hydrogen sulphide,.enters a cooler. There is provision to scrub the cooled gas with wash oil in a tower-type scrubber for removal of light oils (gas spirits, etc.). Light oils can be stripped from the enriched wash oil by means of steam, and after separating water stored in an underground well. A part of the purified gas goes to the holder and the rest goes to the oven via the 6 in. main for heating purposes.

TAR AND LIQUOR SEPARATION SYSTEM

Tar and liquor condensed in the hydraulic and foul gas mains flow continuously into a 'tar catch tank' (also called shoe tank or thick tar container). The condensates from primary cooler, electrodetarrer, exhausters and final cooler flow into a low level tank. The condensate is then pumped into the overhead tar catch tank from which tar and liquor flow into a tower-type decanter where tar and liquor separate, the former remaining at the bottom and the latter over flowing at the top. When sufficient quantity of tar accumulates in the decanter, it is transferred into a horizontal tar tank of 6000 gal. capacity. A part of the liquor is pumped for spraying into the hydraulic main, foul gas main and governor, the remaining going to the drain.

The essential units of the byproduct plant, designed to handle 17,500 cu. ft of gas per hour, are described below:

Primary Cooler. It is an indirect type, horizontal, water-tube cooler, water flowing inside the tubes and gas outside. The total cooling surface provided is 50 sq. m. and overall height of the unit is about 10·4 m.

Electrodetarrer. It is a tube-type electrostatic tar precipitator in which gas ascends through a number of vertical tubes (total 20), containing electrode wires suspended in the middle.

Gas Exhausters. Two Bryan-Donkin positive-displacement-type gas exhausters are installed, one of them as a stand-by. It is capable of handling 2700 to 8700 cu. ft of gas per hour at 32 in. w.g. pressure.

Final Cooler. It is of the same type as the primary cooler, but the cooling surface is much less about 30 sq. m. Overall height is about 4·1 m.

Ammonia Washer. It is a tower-type washer of 40 in. diam. and 47 ft height. It is packed with 1 in. × 1 in. raschig rings in four stages. Gas enters the washer at the bottom and leaves at the top. Cold water is sprayed at the top and ammoniacal liquor is taken out at the bottom.

Purifier House. The gas purification unit to remove hydrogen sulphide consists of four tower-type cylindrical boxes, each being 3 m. in diam. and 2·6 m. height. The material used is spread in six trays, placed one over the other at regular intervals. The direction of flow of gas, either in each tower or in the entire system can be reversed.

Light Oil Scrubber. It is a tower-type washer packed with 1 in. × 1 in. raschig rings. The scrubber is 20 in. in diam. and 30 ft in height.

Gas Holder. The holder is single lift, spirally-guided type, with a total capacity of 25,000 cu. ft of gas. At the outlet of the holder, the static pressure of the gas is 12 in. w.g.

Besides these units there are two liquor pumps, two condensate pumps, two benzolized oil pumps, two debenzolized oil pumps and two tar pumps (in each case one pump acts as stand-by).

INSTRUMENTATION AND SAFETY

The plant is provided with following instruments: (*i*) gas flow recorders for production and heating gases, (*ii*) water flow recorder for ammonia washer, (*iii*) steam flow indicators for the retort house and byproduct unit, (*iv*) air flow recorder for the gas burners used for heating the retorts, (*v*) gas flow recorder for the recirculation gas, (*vi*) air and gas pressure indicators, (*vii*) chimney suction gauge, (*viii*) Arkon pressure-cum-vacuum recorder for foul gas main, (*ix*) automatic gas suction regulator, and (*x*) thermometer and pressure gauges at different points in the byproduct plant.

The following safety devices have been provided: (*i*) an automatic gas shut-down valve fitted in the fuel gas line to stop gas supply to the burners in case of failure of power or air or gas supply, (*ii*) a steam-door interlock system fitted to the coke discharge door of the coke chamber so that the door cannot be opened when steam supply is cut off, (*iii*) a water-sealed gas relief valve on the hydraulic main, which opens up automatically when too much pressure is generated in the main either due to local explosion or the failure of exhauster, (*iv*) double explosion relief spring loaded valve which also opens, when there is any explosion in the offtake pipes or gas collecting main, and (*v*) automatic detarrer tripping device, which operates when there is any short circuiting between the electrodes and the earthed body.

SPECIAL FEATURES

The normal throughput of the prototype plant with non-caking and weakly caking coal is 10 tons/retort/day. Provision has been made to inject gas at the bottom of one of the retorts for obtaining higher coal throughput of about 15 tons/retort/day. The improvements have been covered under Indian Pat. Appl. No. 68680.

Another special feature of the plant is the use of synthetic catalyst, developed and patented by the Institute (Indian Pat. Appl. No. 55816), in the byproduct unit for the removal of hydrogen sulphide from the gas.

OTHER AUXILIARY UNITS

(1) A forced draught type concrete cooling tower with a capacity of 30 cu.m./hr has been installed to supply cooled water required for circulation and washing in the byproduct unit.

(2) A producer gas plant with static grate and manual deashing system has been installed to supply lean gas (120-125 Btu/cu. ft calorific value) to the plant for carbonization in case of emergency. The capacity of the generator is 16,000 to 18,000 cu. ft per hour at 64 in. w.g. pressure. The plant is complete with fuel (coke) preparation section, gas cooling and purification system.

(3) Steam generating section: Two Cochrane boilers (one stand-by) supplies steam at 1700 lb./hr at 100 p.s.i.g. pressure.

PRELIMINARY TRIALS WITH SOME BIHAR AND BENGAL COALS

The preheating operation of the ovens began in the last quarter of

1960 and was completed by the middle of January 1961, when trial runs on carbonization were started. The following thirteen low rank, high moisture, high volatile, non-caking and weakly caking coals have been studied so far: (1) Argada seam coals from Argada, Bhurkunda, Sirka, Saunda, Gidi 'A' and 'C' collieries of Bokaro-Ramgarh-Karanpura (B.R.K.) fields, Bihar (Total: 6 samples); (2) Sirka seam coals from Bhurkunda, Saunda, Gidi 'A' and 'C' collieries of B.R.K. field, Bihar (Total: 4 samples); and (3) Koithee seam coal from Jamuria colliery, New Satgram seam coal from Satgram colliery, Lower Dhadka seam coal from Joyram-danga colliery, all of Raniganj field, West Bengal (Total: 3 samples).

PROPERTIES OF COALS

The data on proximate analysis and caking index are given in Table 1.

The calorific values of the coals on air-dried basis varied from 10,870 to 11,320 Btu/lb. Some coals from B. R. K. coalfields were carbonized both as such and after washing in the 40 tons/hr coal washing pilot plant at the Institute.

The range of yields of coke, tar and gas per ton of coal carbonized is given in Table 2.

B. R. K. coals gave a higher yield of coke and lower yields of tar and gas than the Raniganj coals. Differences in the properties of the two groups of coals justify the difference in the results obtained.

The nature of coal carbonized, its throughput and the final temperature to which coke mass is subjected determine the actual yield of various products. Maintaining the flue temperatures as stated earlier and increasing the throughput for a particular coal, the yield of coke on the basis of both unit time and unit ton of coal carbonized increases as also the volatile matter of coke the total yield of gas and the quantity of surplus gas increase per unit time, but decreases per unit ton of coal carbonized. The calorific value of gas is low at lower coal throughputs. By increasing coal throughput the yield of tar per ton of coal and per unit time increases.

PROPERTIES OF COKES

The bulk density of the cokes varied between 30 and 35 lb./cu. ft. The cumulative screen analysis of the coke was found to vary as: (*i*) +1 in. size—81 to 93 per cent; (*ii*) +0·75 in. size—85 to 95 per cent; (*iii*) +0·5 in. size—92 to 97·5 per cent.

Plus 1 in. coke fraction was subjected to 4 drops in the standard shatter test equipment. The shatter values ranged as (*i*) +1 in. Shatter Index—82 to 90 per cent; (*ii*) +0·5 in. Shatter Index—94 to 97 per cent. The proximate analysis and calorific values of cokes produced at optimum throughputs

TABLE 1—PROXIMATE ANALYSIS OF COALS TESTED

SOURCE OF COALS	MOISTURE %	ASH %	VOLATILE MATTER %	FIXED CARBON %	B.S. CAKING INDEX
B. R. K. coalfields	2·7-5·3	14·3-26·7	29·2-33·7	42·0-50·8	4-5
Raniganj coalfield	1·4-4·0	18·7-20·9	31·8-33·5	41·4-44·2	3-10

TABLE 2—YIELDS OF PRODUCTS

SOURCE OF COALS	COKE cwt	TAR gal.	GAS OF 450-500 Btu/cu. ft CALORIFIC VALUE, cu. ft
B. R. K. coalfields	14-16	12-13	4500-7000
Raniganj coalfield	13-14	15-16	6500-9000

are: moisture, 1-6%; ash, 21-33%; volatile matter, 6·5-10%; fixed carbon, 53-73%; calorific value, 9140-10910 Btu/lb.

PROPERTIES OF TARS

The specific gravity of wet tars with a water content of 2-8 per cent varied from 1·02 to 1·03 and that of dry tars from 1·03 to 1·04. The amount of total solids insoluble in toluene in dry tars varied from 0·6 to 0·7 per cent. On distillation, the dry tars gave 60-65 per cent tar oils. The tar oils consisted of 19·5-23 per cent tar acids, 2·6-3·0 per cent tar bases and the rest neutral oils. Of the total tar acids, 12·6 to 17·3 per cent distilled below 215°C. Neutral oils on fractional distillation yielded 15 per cent boiling up to 195°C., 30-35 per cent boiling between 195 and 270°C., and 40-50 per cent boiling between 270 and 360°C., leaving behind a small amount of residue. Apart from the above-mentioned laboratory study a 30-ton lot of the plant tar was tested, in a reputed local commercial plant with a capacity of 20 tons/day.

The results of these trials, which have been briefly presented in the paper, have demonstrated that the plant can successfully carbonize the wide range of coals tried, at high throughputs of more than 10 tons per retort per day and that coke, the main product of carbonization is highly satisfactory from the view point of household use.

ACKNOWLEDGEMENT

The authors wish to acknowledge gratefully the help received from Mr M. J. Sanders, the representative sent by the Fuel Research Station,

U. K., under the Colombo Plan. The assistance from the staff of the l.t.c. and byproducts plant is also duly acknowledged.

REFERENCES

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DISCUSSION

Dr S. K. Sircar: I find that most of the coals tested can be considered as of good quality with comparatively low ash. For domestic purposes, coke from such coals is not used. I would like to know whether coals of the type as we use for domestic purposes in the form of soft coke, (i.e. with an ash content of 30-40 per cent) have been tried and if so with what results. I am particularly interested to know whether such coals give sufficient gas to meet the heat requirements of carbonization.

Shri H. C. Chakrabarti: Coals with ash content up to 27 per cent have been tried. The gas yield depends primarily on the volatile matter of coal. While carbonizing coal with 28-29 per cent volatile matter content the gas was just sufficient for heating up the retort.

Dr S. M. Prasad: The tar yield given for some coals from the B. R. K. region is 6 per cent (12-13 gal./ton) and is rather low. The economics of l.t.c. is based on the returns from liquid byproduct. I would like to know whether there is any other process to improve the yield of tar.

Shri H. C. Chakrabarti: It was difficult to get sufficient quantities of coals from this region for the tests. If large quantities of coal could be made available, systematic tests can be carried out. The results reported here are only from the preliminary trial runs. The byproduct section has now been modified to recover the entire tar and yields of 16 gal./ton have been obtained.

Shri D. P. Agrawal: The authors stated that by increasing coal throughput, the yield of tar per ton of coal carbonized per unit time increases. The author may kindly explain this observation.

Shri H. C. Chakrabarti: As the throughput increases, the yield of semicoke increases and this can be considered as true low temperature carbonization. If the throughput is decreased, conditions favour high temperature carbonization with more of cracking yielding more gas and less tar. Hence by increasing throughput, optimum conditions for l.t.c. are maintained resulting in less cracking; consequently the yield of tar is increased.

Dr S. H. Zaheer: I would like to have more information on the screen analysis of coal and semicoke, the thermal efficiency while carbonizing different types of coals, composition of the gas, the type of refractory material used and their resistance to temperature and abrasion in the narrow brick retort.

Dr R. Vaidyeswaran: Supplementing the previous question, I wish to know the tar yield referred to Gray-King assay, the amount of surplus gas available and the ignition properties of the semicoke (i.e. its ignition point or C.A.B. value).

Shri H. C. Chakrabarti: Systematic investigations are being carried out with Raniganj coals and they will be published in the form of reports. Thermal efficiency is about 88-89 per cent. The composition of the fire bricks is 60 per cent SiO_2 and 38 per cent Al_2O_3 and these are standard fire bricks. No deterioration has so far been noticed with these fire bricks. The plant has been in operation for one year continuously and the temperature in the flues is about 1150°C.

The yield of tar is 70 per cent on Gray-King assay. The C.A.B. value of coke is 0·01-·02 cu.ft/min. The surplus gas depends on the volatile matter of coal. With Raniganj coals having 34 per cent volatile matter the production amounted to 34 therms/ton of coal and the consumption 20-21 therms.

Dr K. Y. Shrikhande: The pilot plant has been in operation since January 1961 and the difficulty has been to get coal in large quantities and therefore data for different coals could not be given. In October 1961, a 3-day test was done with Jambad-Bowlah coal and the results are as follows when the plant was operated at a throughput rate of 10 tons per retort per day.

Analysis of Coal:

Moisture	5·4%
Ash	15·7%
Volatile matter	36·0%
Fixed carbon	42·9%
Calorific value	10,960 Btu/lb.
Coal + 3 in.	10%
+ 1 in.	96%
Bulk density of charge	45·3 lb./cu. ft
Yields: coke	13·4 cwt
heavy tar	17 gal.
light tar	22·4 gal.
gas	6450 cu. ft
Gas production	34·5 therms
Consumption	21·0 therms
C. V. of gas	535 Btu/cu. ft

Analysis of gas, %:

CO_2	11·6
C_nH_m	3·0
O_2	0·6
CO	10·0
CH_4	31·0
H_2	41·2
N_2	2·6

Screen analysis of coke, %:

+ 3 in.	2·1
+ 2 in.	30
+ 1½ in.	66
+ 1 in.	92
+ ¾ in.	96
+ ½ in.	97
— ½ in.	3

Bulk density of coke: 34 lb./cu. ft

Shatter test (done on +1″ size, 4 drops)

	(1) %	(2) %
+ 2 in.	10	14
+ 1½ in.	40	39
+ 1 in.	86	86·6
+ ½ in.	95·4	95·8

Pilot Plant Studies on Low Temperature Carbonization of Indian Coals: Part I-Lurgi-Spuelgas Process and Operational Data

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Data on pilot plant studies on low temperature carbonization of non-caking and weakly caking coals from Tandur, Kothagudem, Mandamari coalfields in Andhra Pradesh, Ghughus colliery in Maharashtra and Jambad-Bowlah and Upper Kajora from Raniganj area are presented. A satisfactory and clean smokeless fuel for open-grates was produced by carbonizing at 650°-750°C. in the Lurgi-Spuelgas type carbonizer. The semicoke burned in open-grate without any smoke or smell and was strong enough to withstand handling and transport. The studies established the economic feasibility of large-scale low temperature carbonization industry in India. The operational data of plant and yields are discussed.

A characteristic feature of the pattern of energy consumption in underdeveloped countries is the widespread use of non-fossil fuels such as farm waste, animal-dung, wood and charcoal. In India, coal, oil and hydropower contribute only about 30 per cent of the total energy consumed, the remaining being met by agricultural fuels; this excludes the large proportion of animate energy now in use. The serious consequences which India is suffering as a result of the continuous and extensive deforestation and soil erosion are well known. The widespread use of cattle dung as fuel, estimated to be about 250 million tons (dry) per annum, has also resulted in loss of soil fertility. Serious thought is at present being given to change the energy pattern from a 'non-fossil fuel basis' to 'fossil fuel basis'.

Assuming that even after a change in the energy pattern in favour of the use of fossil fuels, and that a substantial proportion of the population of villages and small towns continue to use wood as fuel, it is estimated that about 100 million tons coal-equivalent per annum would be required to meet the energy demands of the domestic sphere. The estimated reserves of coal in India are about 50,000 million tons, of which only about 4 per cent constitutes coking coal. The reserves of noncoking and low-grade coals are, on the other hand, extensive. To meet the energy demands of the domestic sphere, emphasis should therefore be laid on the almost exclusive use of these coals as raw materials. The main processes suitable to these coals are low temperature carbonization (l.t.c.) and complete gasification producing semicoke and fuel gas respectively for use as domestic and industrial fuels. Pilot plant studies on the l.t.c. of some Indian coals are reported in this paper.

LOW TEMPERATURE CARBONIZATION PROCESSES

L.t.c. processes can be broadly classified on the basis of the heating system used, into (1) external heating, (2) internal heating, and (3) combination of external and internal heating processes. Depending on the design details of the plant, material of construction, operational details and type of material to be used for carbonization, these processes can be further subdivided as:

(1) vertical, horizontal or inclined retorts;
(2) moving or stationary retorts;
(3) continuous or intermittent operation; and
(4) metal or brick retorts.

Out of the 250 or more l.t.c. processes developed for carbonizing brown coal, lignite, bituminous coal and other carbonaceous materials, a few commercially exploited processes like the Disco (U.S.A.), Coalite (U.K.), Rexco (U.K.), Fuel Research Board (U.K.), Krupp-Lurgi (Germany), Lurgi-Spuelgas (Germany) and Koppers (Germany) may be particularly mentioned. Merits and demerits of these processes have been discussed earlier[1,2].

In all these processes the quality and quantity of semicoke, tar and gas obtained mainly depend upon (1) the process used, (2) temperature of carbonization, and (3) type of coal carbonized.

WORK IN INDIA

More than 2 million tons of soft coke are being produced from weakly caking coals in the Bengal-Bihar coalfields region by the unhygienic and wasteful method called "open stack burning". During 1939-45, for the first time, a scientific attempt was made by the late Dr H. K. Sen to tackle the domestic fuel problem by replacing cow-dung and firewood with a smokeless semicoke. He also set up a small experimental l.t.c. unit at the Indian Lac Research Institute, Ranchi.

After preliminary investigations on l.t.c. of non-caking coals available in Andhra Pradesh, this Laboratory decided as early as 1950 to set up a pilot plant for l.t.c. of these coals to study the quality of solid and liquid products and economics of the l.t.c. industry. A Lurgi-Spuelgas l.t.c. pilot plant was erected and commissioned into operation in December 1953. Since then the plant has been in regular operation; five non-caking coals and one weakly caking coal from different parts of India have been tested for their suitability to l.t.c.

DESCRIPTION OF THE PLANT

The pilot plant is based on the Lurgi-Spuelgas internal heating system with a rated capacity of 25 tons of sized coal (30-80 mm.) per day. The main plant consists of a vertical shaft in three sections the drying zone at the top, the carbonizing zone in the middle and the coke cooling zone at the bottom and a condensation system consisting of a precooler, a tar separator and a pipe cooler. The inside dimensions of these units are: dryer, 1750 mm. × 1470 mm. × 4520 mm. ht; carbonizer, 1750 mm. × 1400 mm. × 2530 mm. ht; coke cooler, 1750 mm. × 1400 mm. × 850 mm. ht; precooler, 1000 mm. diam. × 3600 mm. ht; pipe cooler, 1500 mm. diam. × 8500 mm. ht.

The drying and carbonization sections have two burners attached externally at the sides. The drier, carbonizer and burner chambers are of mild steel shell lined inside with low and high duty refractory bricks and insulation bricks conforming to the Indian Standard Specification. The precooler is an empty m.s. tower, the bottom part of which is lined with acid-proof refractory bricks to prevent corrosion. The tar separator is a small m.s. tower, the upper part of which is packed with raschig rings; the bottom part contains a rotating drum in a tar seal. The pipe-cooler is of the shell-and-tube type and made of mild steel. The total height of the main unit is 20 m.

In addition to coal and coke crushing, screening and conveying systems, the plant is provided with other accessories like control and instrument panel, pump house, storage tanks, gas producer, boiler and water cooling tower.

The total floor area of the plant excluding coke and coal storage yard is about 1400 sq.m. A layout of the main plant is shown in Fig. 1. Illustrations of screening unit, coal and coke yard and the main plant are shown in Figs. 2, 2A and 2B.

The plant has the following special design features which make it suitable for a variety of operating conditions:

1. The condensation unit can accommodate a wide range of tar, oil, liquor and gas quantities. The plant can therefore be used for the carbonization of lignite briquettes as well as bituminous coal.
2. The internal parts of the carbonizer can withstand temperatures up to 1000°C.

3. Provision also exists to varying the time of carbonization and the height of carbonization zone.
4. Provision is also made to process caking coals by partial oxidation in the predrying zone to reduce their caking properties.

DESCRIPTION OF THE PROCESS

The process flowsheet is shown in Fig. 3. Raw coal, crushed in a jaw crusher, is carried by a belt conveyor to the vibrating screen situated above the coal bunkers. The crushed coal is screened into two sizes,

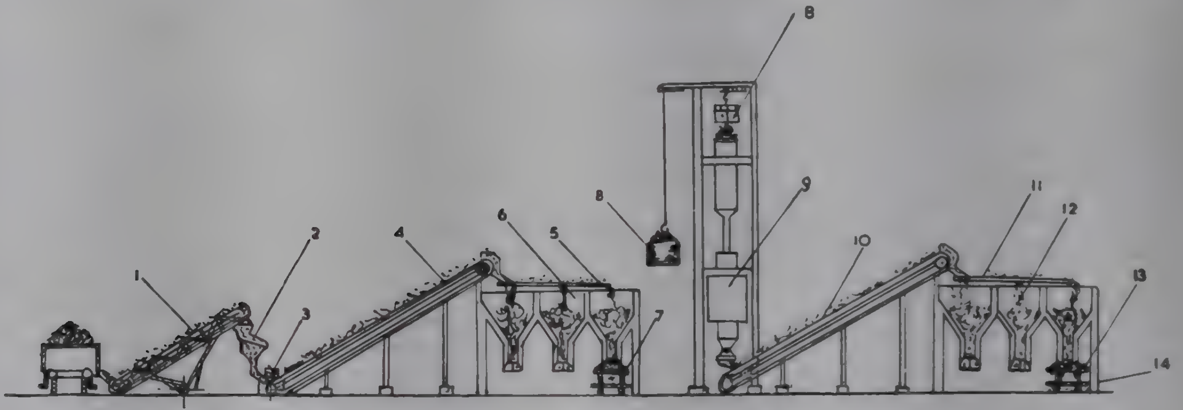

Fig. 1—Layout of L. T. C. plant: (1) Portable belt conveyor (2) Bar grate (3) Crusher (4) Belt conveyor (5) Vibrator (6) Intermediate bunker (7) Gable bottom car (8) Electric hoist (9) Carbonizer (10) Belt conveyor (11) Vibrator (12) Coke bunker (13) Rocker side dump car (14) To coke storage yard

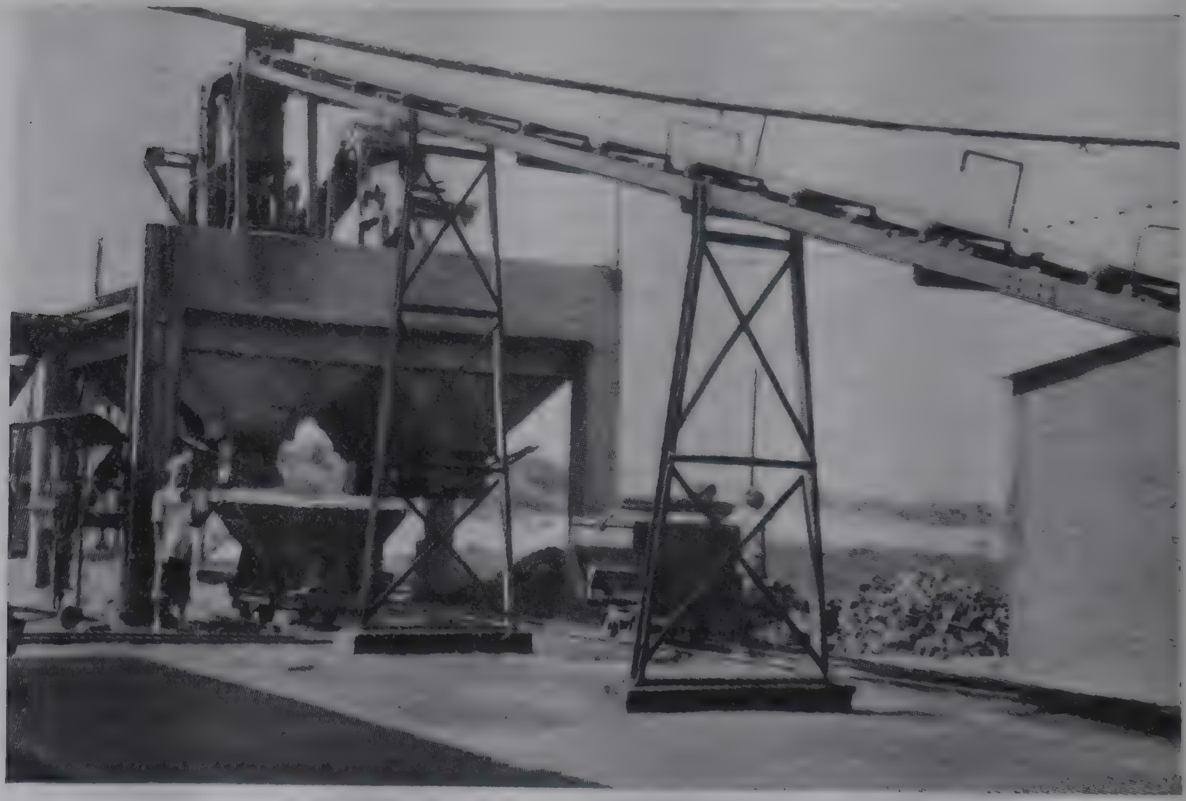

Fig. 2—Coal and coke screening plant

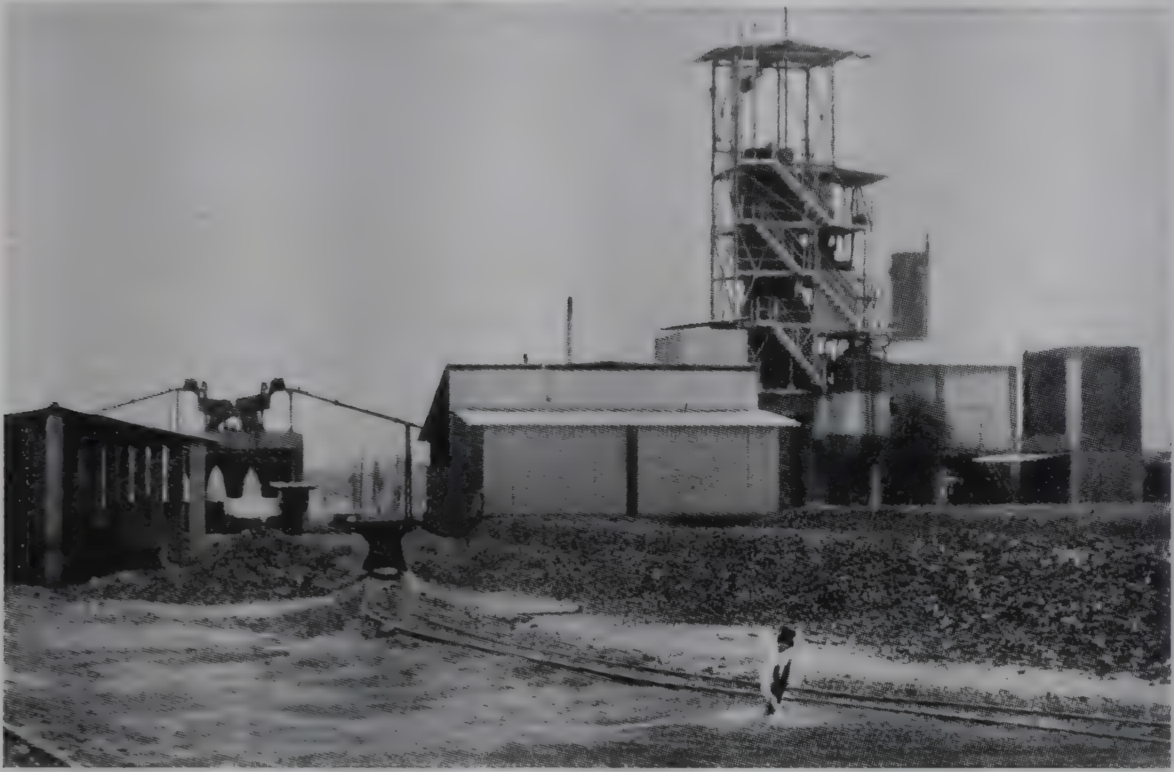

FIG. 2A—COAL AND COKE YARD

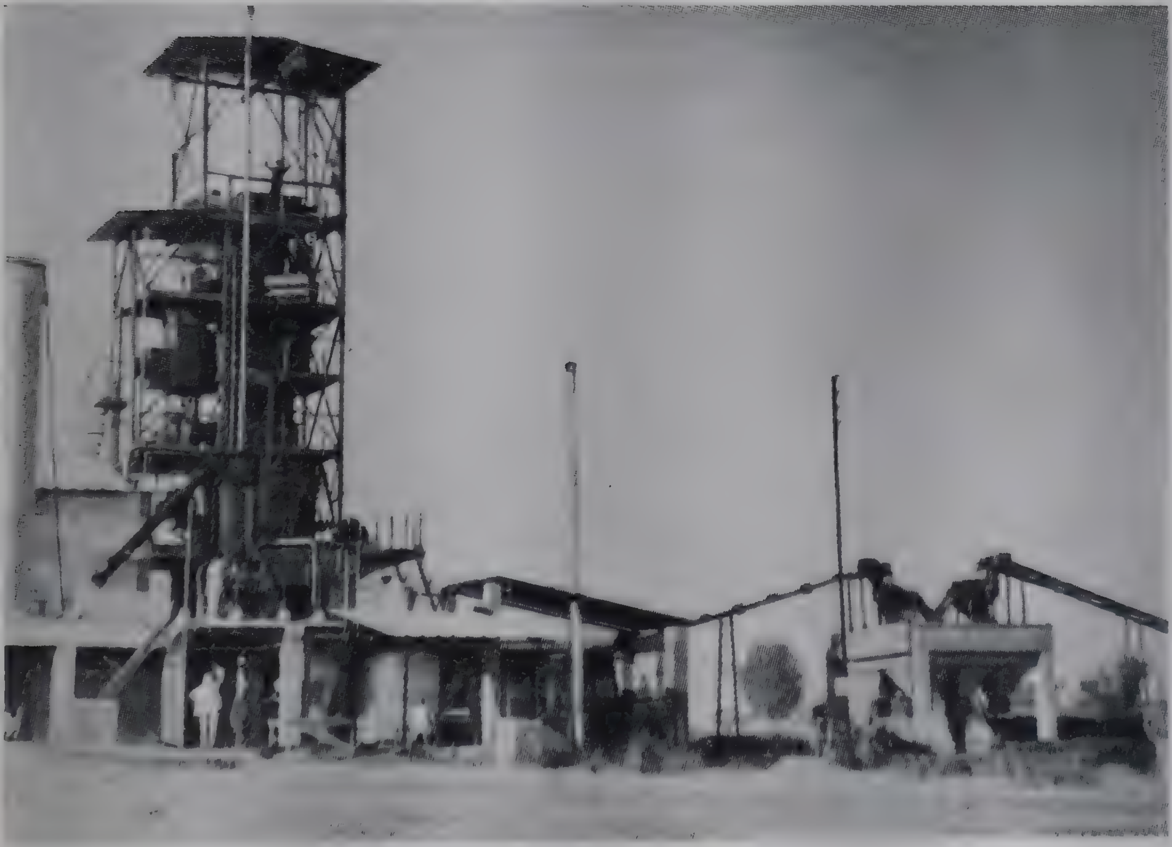

FIG. 2B—CARBONIZATION UNIT

125-25 mm. and 25-0 mm. The larger-sized material is filled into gable bottom cars which are lifted by an electric hoist to the top of the carbonizer where coal is discharged into the bunker (3A, Fig. 3).

The coal moves down slowly due to gravity into the drying zone (3B). Drying is effected by the hot products of combustion generated by burning part of the recirculation gases in the burner (3C). The bulk of the gases in the drying zone are kept in circulation by the fan (5) which is controlled to maintain the required temperature in the zone. Moisture in coal along with the rest of the drying gases escapes through a waste gas chimney at the top.

The dried coal then moves down into the carbonizing zone (8C) where carbonization is effected by a mixture of the hot gases entering from the

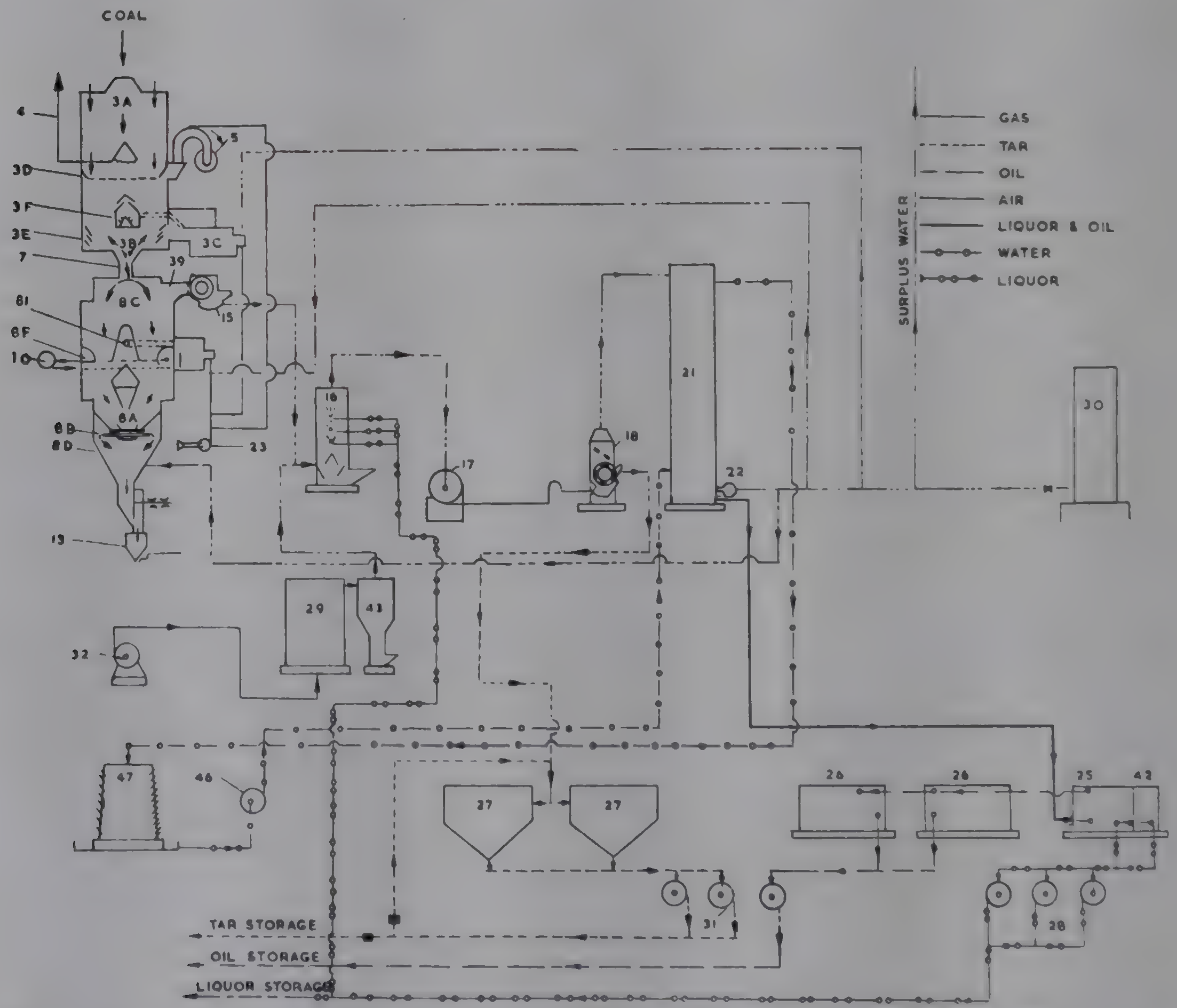
COAL
3A
4
3D
3F
3E
7
3B
3C
5
39
8C
8I
8F
10
15
8A
8B
8D
23
13
16
17
18
21
22
30
SURPLUS WATER
GAS
TAR
OIL
AIR
LIQUOR & OIL
WATER
LIQUOR
29
43
32
47
46
27
27
26
26
25
42
31
28
TAR STORAGE
OIL STORAGE
LIQUOR STORAGE

FIG. 3—FLOWSHEET OF L. T. C. PROCESS: (3) Pre-dryer (3A) Charging bunker (3B) Drying zone (3C) Drying combustion chamber (3D) Cyde roofs (3E) Lower inlet roofs (3F) Upper inlet roofs (4) Waste-gas pipe (5) Pre-dryer fan (7) Connecting shaft (8) Carbonizer (8A) Coke-cooling zone (8B) Dig placer (8C) Carbonizer zone (8D) Cooling gas inlet pipe (8F) Cooling gas outlet channel (8H) Combustion chamber (8I) Hot gas grate (10) Cooling gas fan (13) Coke lock chamber (15) Dust separator (16) Pre-cooler (17) Hot gas fan (18) Tar separator (21) After-cooler (22) Entrainment separator (23) Air fan (25) Separating tank for oil and aqueous distillate (26) Oil tank (27) Tar tank (28) Pumps for aqueous distillate (29) Gas producer (30) Steam boiler (31) Pumps for tar and oil (32) Gas producer air fan (39) Carbonizer gas outlet (42) Tank for aqueous distillate (43) Dry dust separator (46) Pumps for cooling water (47) Cooling tower

carbonizer burner chamber (8H) and the gases drawn from the coke cooling zone (8A) after extracting the heat from the hot coke. The requisite quantity of heat for carbonizing the coal is supplied by controlling the proportion of the two gas components. The circulation of gases and the pressures in the drier and carbonizer are controlled by the fans (5) and (10) separately in such a way that the rich gases from the carbonizer zone do not enter the drying zone, and the waste gases from the drier are not sucked down into the carbonizer.

The coke now moves down into the cooling zone (8A), where a part of the pure heating gas is admitted at atmospheric temperature to cool the coke below 80°C. The gases rising upwards in the coke-cooling zone are heated to about 400°C., and are circulated by the fan (10) into the carbonizing zone. The coke is collected in a lock chamber (13) by a continuous automatic discharge drive (8B) which is regulated to control the throughput of the plant. The coke is periodically discharged manually on the belt conveyor and quenched further with water spray. The belt conveyor discharges the coke on a screening unit fixed on top of the coke bunkers. Coke is separated here into two sizes (above and below 19 mm.). Arrangement is also provided to screen the coke into three sizes, +19 mm., 10-19 mm., and below 10 mm.

The total interval of time between the feed of coal into the bunker and discharge of coke is about 12-13 hr and the time of residence of coal in the carbonization zone is estimated to be about 3-4 hr.

The carbonization gases admixed with the heating gases leave the carbonizer at the top and pass through a dust separator (15) where they are drawn through a perforated drum rotating in a water seal. Most of the dust in the gases is collected here. The gases then enter the precooler (16), where they are cooled to the tar humidity point (120° to 150°C.) by spraying ammoniacal liquor, if necessary. The gases are now drawn off by a fan (17) and blown through the tar separator (18) and the water-cooled pipe condenser (21). The fraction of tar collected at the bottom of tar separator is syphoned off continuously through steam-heated pipes into storage tanks (27). This fraction is known as heavy tar. In the pipe cooler gases are cooled outside the pipes so as to condense ammoniacal liquor and oil. This oil is known as light tar.

The mixture of liquor and light tar is sent to automatic settling and separation tanks (25) and (26). The gases leaving the pipe condenser still contain some entrained moisture and oil mist which are removed in the entrainment separator (22). The gas is then sent to the control panel for distribution to the drier burner, carbonizer burner and coke cooling zone. The excess gas is burnt in open flame above the tower roof in this plant. This gas can be used for heating purposes, its calorific value is similar to that of producer gas, depending upon the type of coal carbonized and the temperature of carbonization.

A producer (29) is provided for the initial starting of the plant and for use in emergency. A boiler (30) and a water cooling tower (46) are provided for steam and water requirements of the entire plant.

TESTS

Six coals from Kothagudem, Tandur and Mandamari coalfields in Andhra Pradesh, Ghughus colliery in the Maharashtra State and Jambad-Bowlah and Upper Kajora coalfields from Raniganj area were tested. Proximate analyses of these coals are presented in Table 1 and screen analysis in Table 2.

Complete operational data were recorded when steady conditions were reached. Typical data on temperature, pressure and flow of gases are given in Table 3.

Heavy tar samples were collected from the steam-heated tar pipe leading to the tar tank for 10 minutes every hour and the weight rate of

TABLE 1—PROXIMATE ANALYSIS OF COAL

(air-dried basis)

Source of coal	Moisture %	Ash %	V.M. %	F.C. %	C.V. Btu/lb.
Kothagudem	5·1	19·6	26·4	48·9	10,550
Tandur	6·3	19·7	28·7	45·3	10,120
Mandamari	3·8	20·8	29·8	45·6	10,200
Ghughus	11·5	16·6	30·2	41·7	9,410
Jambad-Bowlah	5·4	14·2	35·0	45·4	11,320
Upper Kajora	5·3	17·6	32·7	44·4	10,620

TABLE 2—SCREEN ANALYSIS OF COAL

(wt %)

Source of coal	+4 in.	+3 in.	+2 in.	+1½ in.	+1 in.	+1/2 in.	+1/4 in.	+1/8 in.	—1/8 in.
Kothagudem	..	..	26·1	20·9	21·4	24·1	4·2	2·1	1·2
Tandur	..	6·5	38·7	27·6	17·1	10·1	..	..	..
Mandamari	2.0	20·0	40·0	..	30·0	4·0	1·0	0·5	0·5
Ghughus	3.0	32·0	34·0	..	27·0	2·0	1·0	0·5	6·5
Jambad-Bowlah	..	1·5	35·3	35·6	22·0	5·6	..	..	..
Upper Kajora	..	1·1	35·5	32·6	25·1	2·9	0·6	1·0	1·3

TABLE 3—TYPICAL GENERAL OPERATIONAL DATA

SOURCE OF COAL	KOTHAGUDEM	TANDUR	MANDAMARI	GHUGHUS	JAMBAD-BOWLAH		UPPER KAJORA
Temperatures, °C.							
(*a*) Carbonization zone	640	650	650	650	750	650	650
(*b*) Predryer	190-210	185-200	190-210	175-185	250	250	220
(*c*) Condensation of tar	110-114	140-144	114-120	125-130	115-120	115-120	115-120
(*d*) Carbonizer gas outlet	245	260	230	220	280	270	255
Pressure in carbonizer (mm. water)	0-5	10-15	5	5-10	5-10	5-10	5-10
Carbonizer Burner gas:							
(*a*) Pressure (mm. w.g.)	150	150	100	230	350-360	440	230-240
(*b*) Gas consumption (cu. m./ton feed coal)	129·6	158·3	100	158	189	184	156
Dryer Burner gas:							
(*a*) Pressure (mm. w.g.)	250	150	150	470	410	420	550
(*b*) Gas consumption (cu. m./ton feed coal)	167·6	158·3	163	227	203	207	238
Cooling gas:							
(*a*) Pressure (mm. w.g.)	420-440	270	300	380	350-360	880	480
(*b*) Gas consumption (cu. m./ton feed coal)	856	881	923	807	752	880	880
Excess gas:							
(*a*) Pressure (mm. w.g.)	150	100	100	100	370	350	400
(*b*) Gas (cu. m./ton feed coal)	109	87	123	108	179	174	188
Utilities:							
(*a*) Electric power, Kwh/day	700	same as for Kothagudem coal					
(*b*) Water (make-up), gal./day	3000						
(*c*) Steam (40 psig), ton/day	1·5-2·0						

TABLE 4—GAS FLOW INTO THE DIFFERENT ZONES OF THE LURGI-SPUELGAS PLANT

(Basis: per ton of coal carbonized)

Source of coal	Kothagudem		Tandur		Mandamari		Ghughus		Jambad-Bowlah				Upper Kajora	
Temp., °C.														
Carbonizer	650		650		650		650		750		650		650	
Drier	200		200		210		185		250		250		220	
Zone	Therms	%	Therms	%	Therms	%	Therms	%	Therms	%	Therms	%	Therms	%
Coke cooling zone	38·4	65·9	28·0	67·2	48·2	70·5	17·4	51·6	48·1	57·0	43·5	60·9	35·7	60·2
Carbonizer burner	5·6	9·6	5·0	11·9	5·3	7·7	5·4	15·8	12·1	14·3	9·1	12·7	9·7	16·3
Drier burner	9·6	16·4	5·0	11·9	8·5	12·5	7·7	22·7	12·9	15·3	10·2	14·4	6·3	10·6
Excess	4·7	8·1	3·7	9·0	6·4	9·3	3·3	9·9	11·4	13·4	8·2	12·0	7·6	12·9
Total	58·3	100·0	41·7	100·0	68·4	100·0	33·8	100·0	84·5	100·0	71·0	100·0	57·3	100·0

TABLE 5—YIELDS OF PRODUCTS FROM PILOT PLANT TESTS PER 100 TONS OF COAL FEED

Source of coal	Carbonization temp., °C.	Semicoke, tons	Heavy tar, tons	Light tar, tons	Surplus gas, cu.m.
Kothagudem	640	73·00	3·86	2·02	10,900
Tandur	650	64·12	4·08	3·12	8,730
Mandamari	650	71·20	4·05	2·44	12,300
Ghughus	650	62·32	3·20	3·10	10,800
Jambad-Bowlah	650	64·49	4·53	4·25	17,400
	750	64·45	4·47	5·36	17,900
Upper Kajora	650	63·84	4·04	4·16	18,800

flow was recorded; light tar and liquor were collected together from the pipe cooler for 15 minutes every two hours and the oil separated and weighed. Light tar collected from the drain pipes during the whole shift was weighed separately.

Since it takes 12 to 13 hr for the coal to move from the coal hopper to semicoke discharge, the yields of semicoke obtained 12 hr after the coal feed were taken for calculation of percentage yields. In the case of heavy and light tars, however, yields were calculated on the basis of samples collected 8 hr after the coal was fed into the coal hopper.

RESULTS AND DISCUSSION

The pattern of gas distribution into the four different zones of the plant is given in Table 4. The maximum thermal value of gas is obtained

TABLE 6—SCREEN ANALYSIS OF SEMICOKE
(wt %)

SEMICOKE OBTAINED FROM COAL	TEMP. OF CARBONIZATION, °C.	+3 in.	2-3 in.	1½-2 in.	1-1½ in.	½-1 in.	¼-½ in.	⅙-¼ in.	−⅛ in. cwt losses
Kothagudem	640	..	4·9	7·4	15·5	42·2	11·3	11·8	6·9
Tandur	650	0·4	14·3	25·4	30·4	18·5	3·0	3·9	4·1
Mandamari	650	4·0	20·0	..	48·0	15·0	8·0	2·0	3·0
Ghughus	650	2·0	15·0	..	39·0	22·0	10·0	7·0	5·0
Jambad-Bowlah	650	0·2	20·4	21·0	28·4	15·3	3·9	5·9	4·9
	750	..	9·7	29·1	34·5	15·0	2·9	4·3	4·5
Upper Kajora	650	..	5·4	20·4	37·9	24·8	3·1	4·2	4·2

TABLE 7—PROXIMATE ANALYSIS OF SEMICOKE
(air-dried basis)

SEMICOKE OBTAINED FROM COAL	TEMP. OF CARBONIZATION, °C.	MOISTURE %	ASH %	V.M. %	F.C. %	CALORIFIC VALUE, Btu/lb.
Kothagudem	640	2·8	22·6	8·1	66·5	11,440
Tandur	650	2·7	25·7	8·4	63·2	9,770
Mandamari	650	2·7	23·8	10·1	63·8	9,840
Ghughus	650	3·6	24·9	10·9	60·6	9,670
Jambad-Bowlah	650	2·5	20·2	9·5	67·8	11,420
	750	2·6	21·1	4·7	71·6	10,820
Upper Kajora	650	2·7	26·2	6·9	64·2	10,110

from Jambad-Bowlah coal from Raniganj and Mandamari coals from Andhra Pradesh. Due to the poor calorific value of the gas from Ghughus coal and also the high moisture content of coal, a much larger proportion of the total gas was required for heating purposes. The fact that the major part of the gas is readmitted into the coke-cooling zone, and circulated through the carbonization zone shows the importance of recirculation in waste heat recovery and efficient carbonization.

The average percentage yields of products obtained are presented in Table 5. The yields of semicoke are in general about 64 per cent except in the cases of Kothagudem, Mandamari and Ghughus coals. The high figure for Kothagudem coal was due to the lower size range of feed coal. Mandamari coal appears to give the best performance. The screen analysis of semicoke collected on conveyor belt is given in Table 6. The yield of product above 1/2 in. which is saleable as domestic fuel was lowest in the case of Kothagudem coal and highest in the case of Mandamari coal. The yield of product above 1/2 in. which is saleable as domestic coke is on the average about 50 per cent of feed coal. The proximate analysis of semicoke is given in Table 7.

During carbonization of coals from Kothagudem, Tandur, Mandamari and Ghughus coalfields, maintaining a carbonization temperature of 650°C., no operational difficulties were experienced. The semicoke obtained from these coals produced no smoke when subjected to combustion tests in a domestic stove.

In the case of Jambad-Bowlah coal, when carbonized at 650°C., some of the semicoke pieces produced slight smoke on combustion. The following two causes were suspected and conditions were modified accordingly: (1) Initially the size of coal fed varied between 25 and 150 mm. Since smoking was more in large pieces, the maximum size was reduced to about 80-90 mm. (2) Due to the weakly caking properties of the coal, the coal pieces might have been sticking to each other, to form "bridges" and lumps, resulting in channelling of gases and preventing complete carbonization. The drier temperature was therefore raised to 250°C. and the carbonizer temperature to 750°C.

With these modifications the semicoke was found to be carbonized completely and to burn without smoke. It was found unnecessary to admit any oxidizing air into the drier zone to reduce its caking properties. Towards the close of the test the carbonization temperature was reduced to 650°C., maintaining the drier temperature at 250°C. The semicoke obtained under these conditions also burned without giving any smoke.

During preliminary tests, in the case of Upper Kajora coal, it was noticed that a weak button was formed during the determination of volatile matter. Therefore, the carbonizer temperature was maintained at 650°C. and that of the drier at about 220°C. Maximum size of the coal feed was 80-90 mm. The semicoke obtained was smokeless.

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DISCUSSION

Dr M. S. Iyengar: The —0·5-in. fraction in the product (Table 6) appears to be high. How is it disposed off ? The yield of semicoke from Kothagudem coal (Table 5) appears to be higher than with other coals although the Gray-King assays do not indicate any difference. Can this be explained ? Screened coal of 30-125 mm. size is fed to the plant; the semicoke is mostly below 80 mm. and product above this is negligible. Perhaps the size of product could be improved by feeding coal of 1-3 in. I would like to know whether any tests have been done by varying the size of feed ?

Dr M. G. Krishna: Coals from this region are known to be of low rank and large quantities of fines are produced during carbonization. The coal and coke fines are sold to brick industry as fuel.

The higher yield of semicoke from Kothagudem coal is partly due to the small proportion of 10-30 mm. sized material in the feed which acts as a cushion and reduces disintegration. The hardness of the raw coal and its low tar content may also be partly responsible for the higher yield of semicoke. If the coal is hard, the dust carried away by circulating gases will be lesser, thereby increasing the total yield of semi-coke. This aspect is not reflected in the Gray-King assay.

The results on Kothagudem coal pertain to the tests carried out during the first few months of operation of the pilot plant when sized coal (30-80 mm.) was fed according to plant specifications. When the product was marketed, the consumers objected to the small size of semicoke. Consequently the size of feed was increased to a maximum of 150 mm. and a small proportion of 150 mm. can be noticed even now in the product. A few tests with +50 mm. coal feed were also carried out but disintegration was found to be more in this case. Literature also shows that a certain amount of middle sized material is desirable in the feed to act as a cushion. During the passage through the carbonizer, bridge formation is likely and when the bridge collapses, disintegration is likely.

In recent years coal with a maximum size of 125 mm. has been fed and the product passes through 80 mm. Semicoke is screened at 25 mm. Depending upon the efficiency of the screening plant, the product passing through 18 mm. is about 15 per cent. The screen analysis of coal and of product from the same coal are shown in Tables 2 and 6. By feeding coal of 0·5-1·5 in. throughput of plant can be increased.

Pilot Plant Studies on Low Temperature Carbonization of Indian Coals: Part II—Products

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Pilot plant experiments on low temperature carbonization of coals from Kothagudem, Tandur, Mandamari, Ghughus, Jambad-Bowlah and Upper Kajora indicate that these coals can be successfully carbonized in plants working on Lurgi-Spuelgas system. The semicoke can be used as smokeless domestic fuel in place of charcoal. About 75-85 per cent of the potential heat of the raw coal can be recovered in the form of semicoke, tar and surplus gas after meeting the heat requirements of the process. Byproducts can form a great source for the production of chemicals, liquid fuels and other useful products.

The Lurgi-Spuelgas low temperature carbonization (l.t.c.) pilot plant installed at the Regional Research Laboratory, Hyderabad, and its operation were described in earlier publications[1,2,3]. In Part I of this series[4], operational and other data on carbonization of one slightly caking and five non-caking Indian coals from West Bengal, Bihar, Maharashtra and Andhra Pradesh were given. The properties of raw coal, semicoke, heavy tar, light tar, ammoniacal liquor and surplus gas are presented in this paper. The extent of disintegration of coal and semicoke during carbonization, percentage recovery of products and thermal efficiency of the process are discussed.

SAMPLING AND EXPERIMENTAL WORK

Representative coal samples were collected during discharge from bunkers into gable-bottomed trolleys which feed coal to the plant. The coke samples were collected from the conveyor belt, carrying the discharged coke to the screening section and in some cases, after screening and during discharge from the bunkers into trolleys, before being conveyed to storage heaps. Separate samples were collected for screen analysis and shatter test. Samples of heavy tar were collected from steam-jacketed pipes after the tar separator and before discharge into storage tanks. Light tar and aqueous liquor were collected together, and separated and representative samples of each taken for analysis.

Coal and coke samples were subsampled and analysed according to standard procedures[5]. Liquid products were analysed, generally according to the standard methods for tar products[6]. Gas samples were analysed in Hahn's and Haage's gas analysis apparatus.

RESULTS AND DISCUSSION

The analyses of coals are presented in Table 1.

They indicate that all these coals can be classified as high volatile non-caking bituminous coals. Ghughus coal, because of its high moisture content, can be regarded as lower in rank than the other coals.

Analysis of semicokes are given in Tables 2 and 2A. The semicoke obtained in all cases was light grey in colour. Calorific values of semicokes from Kothagudem and Raniganj coals are higher than others. When Kothagudem coal was carbonized at 550° and 580°C., the resulting semicokes, emitted slight smoke during combustion on open grates; the semicokes produced at 600°C. and above did not emit smoke. Increase in time of carbonization at 580°C. by reducing throughput rates did not eliminate smoke emission. When the size of the coal feed was increased, the product at 600°C. even at reduced throughput rates gave slight smoke during combustion. Lighting time for semicoke at 550°C. was less by about 30 per cent compared to that at 650°C. However, the brightness of fire using 550° semicoke lasted for a shorter duration than with the product at 650°C

TABLE 1—PROPERTIES OF COAL

Proximate analysis	Source of coal					
	Kothagudem	Tandur	Mandamari	Ghughus	Jambad-Bowlah	Upper Kajora
Moisture, %	5·1	6·3	3·8	11·5	5·4	5·3
Ash, %	19·6	19·7	20·8	16·6	14·2	17·6
Vol. matter, %	26·4	28·7	29·8	30·2	35·0	32·7
Fixed carbon, %	48·9	45·3	45·6	41·7	45·4	44·4
Calorific value, Btu/lb.	10,550	10,120	10,200	9,410	11,320	10,620

TABLE 2—PROPERTIES OF SEMICOKE

	KOTHAGUDEM	TANDUR	MANDAMARI	GHUGHUS	JAMBAD-BOWLAH	UPPER KAJORA
Temp. of carbonization, °C.	650	650	650	650	650	650
Moisture, %	2·8	2·7	2·7	3·6	2·5	2·7
Ash, %	22·6	25·7	23·8	24·9	20·2	26·2
Vol. matter, %	8·1	8·4	10·1	10·9	9·5	6·9
Fixed carbon, %	66·5	63·2	63·4	60·6	67·8	64·2
Calorific value, Btu/lb.	11,440	9,770	9,840	9,670	11,420	10,110
Sulphur, %	0·24	0·31	0·50	0·62	0·32	0·29
Shatter index on 1 in.	71	82	81	64	83	84

TABLE 2A—PROPERTIES OF SEMICOKE FROM KOTHAGUDEM COAL

Temp. of carbonization, °C.	580 L	600 L	600 H	650 H	750 H
Moisture, %	2·0	2·3	2·8	2·9	2·3
Ash, %	21·7	21·9	21·9	21·6	21·8
Vol. matter, %	8·6	8·0	8·3	6·1	5·9
Fixed carbon, %	67·7	67·8	67·0	69·4	70 0

H and L represent higher and lower throughput rates of the plant.

TABLE 3—CUMULATIVE SCREEN ANALYSIS OF SEMICOKE SAMPLES

(wt % retained on screens)

SCREEN OPENING	GHUGHUS		MANDAMARI	
in.	Semicoke (total)	Semicoke*	Semicoke (total)	Semicoke*
4	Nil	Nil	Nil	Nil
3	2·0	1·0	4·0	3·0
2	13·0	10·0	24·0	24·0
1	55·0	55·0	72·0	72·0
½	77·0	86·0	87·0	89·0
¼	88·0	94·0	95·0	96·0
⅛	93·0	97·0	97·0	97·5

*After screening the —0·5 in. product.

TABLE 4—PROPERTIES OF HEAVY AND LIGHT TARS

	Kothagudem	Tandur	Mandamari	Ghughus	Jambad-Bowlah	Upper Kajora
Temp. of carbonization, °C.	640	650	650	650	650	650
Heavy Tar						
(*a*) Sp. gr.	1·070 (25°C.)	1·065 (30°C.)	1·059 (15·5°C.)	1·070 (15·5°C.)	1·064 (25°C.)	1·063 (25°C.)
(*b*) Benzene insoluble, % wt	1·02	1·30	0·64	1·15	1·16	0·89
(*c*) Flash point, °F.	330	325	353	356	n.a.	n.a.
(*d*) Behaviour on distillation up to 300°C., vol. %	3·2	2·0	9·8	5·4	6·1	5·3
300-355°C., vol.. %	36·3	*21·0	36·8	37·8	34·4	34·0
Residue	60·4 (vol. %)	71·0 (vol. %)	55·4 (wt %)	58·6 (wt %)	62·0 (wt %)	62·5 (wt %)
(*e*) Tar acids in distillate up to 355°C., vol. %	30·0	32·5	28·0	45·0	38·8	37·5
(*f*) Calorific value, Btu/lb.	16,950	16,670	17,770	16,740	16,310	16,170
(*g*) Sulphur, %	0·30	0·30	0·30	0·31	0·27	0·32
Light Tar						
(*a*) Sp. gr.	0·9800	0·9563	0·950	0·9832	0·9705	0·9718
(*b*) Water, vol. %	2·1	1·8	0·8	1·1	1·8	3·2
(*c*) Flash point, °F.	145	134	142	142	n.a.	n.a.
(*d*) Calorific value, Btu/lb.	17,500	16,850	17,160	16,760	16,160	16,240
(*e*) Sulphur, wt %	0·29	0·31	0·37	0·34	0·38	0·27
(*f*) Behaviour on distillation, up to 170°C., vol. %	1·6	2·1	n.a.	0·5	1·2	1·2
170°–270°C.	46·5	58·0	50·1 (up to 235°C.)	52·5	63·3	57·3
270°-300°C.	15·3	16·1	24·9 (235-270°C.)	14·0	11·5	13·5
300°-355°C.	25·0	16·2	7·0 (up to 335°C.)	26·0	15·5	17·2
Residue	11·60 (vol. %)	7·6 (vol. %)	4·35 (wt %)	15·8 (wt %)	9·1 (wt %)	10·35 (wt %)
(*g*) Tar acids in distillate, vol. %	28	33	25	32·5	40	40

*Tar was used as sealing fluid in the dust separator; in other cases water was used.
n.a. = results not available.

The semicoke from Jambad-Bowlah coal carbonized at 600°C. generally gave smoke on combustion. The product at 640°C. was smokeless.

The shatter tests indicate that semicokes from Raniganj coals are stronger than others, probably because of the slight caking property of the coals and the spherical shape of the semicoke pieces. Shatter index (on 1 in.) of Ghughus semicoke is lower, probably because of the high moisture content in the coal; the semicoke pieces were also flaky unlike in other cases.

The screen analysis of semicoke has been given in Part I[4]. Screen analysis of Ghughus and Mandamari semicokes collected before and after passing through the screening plant is presented in Table 3. The results show that (1) almost all the fraction above 3 in. in the coal feed has disintegrated during carbonization and (2) the semicoke screened above 0·5 in. has further disintegrated while falling into bunkers resulting in an increase of the fraction below 0·5 by 8-10 per cent.

The analyses of heavy tar are presented in Table 4. They indicate that the specific gravities of Mandamari and Upper Kajora tars are lower than those of others, probably due to the greater amount of fraction below 300°C. in the tar. The tar acid content in the distillate up to 355°C. from the Ghughus heavy tar is more than in other cases. This may be attributed to the highly oxygenated nature of the coal. Tar acid contents in tars from Kothagudem, Tandur and Mandamari coals (Andhra Pradesh coalfields) are distinctly lower than in the case of tars from the northern coalfields.

Results of analysis of light tar (Table 4) indicate that the specific gravity of tar from Mandamari coal is lower than that of others. This may be due to the lower tar acid content in the distillate and the lower yield of residue. Tar acid contents in Jambad-Bowlah and Upper Kajora tars are higher than in others.

Table 5 gives the analysis of aqueous liquor. No comparison of the results can be made because the amounts of tar acids and ammonia depend, to a great extent, on the dilution of the liquor in the plant which is not possible to estimate.

TABLE 5—PROPERTIES OF AQUEOUS LIQUOR

(Temp. of carbonization, 650°C.)

	KOTHAGUDEM	TANDUR	GHUGHUS	JAMBAD-BOWLAH	UPPER KAJORA
Sp. gr.	1·0137	1·0270	1·0070	1·0150	1·0163
Free ammonia, g./l.	13·61	7·02	4·77	8·64	8·20
Fixed ammonia, g./l.	3·55	5·49	1·87	1·88	2·46
Tar acids, g./l.	6·18	4·97	6·91	5·77	6·51

TABLE 6—COMPOSITION OF EXCESS GAS

	KOTHAGUDEM	MANDAMARI	GHUGHUS	UPPER KAJORA	JAMBAD-BOWLAH
Temp. of carbonization, °C.	650	650	650	650	650
Composition of gas, vol. %					
CO_2	10·5	11·1	13·5	10·8	11·1
C_nH_m	0·5	1·0	0·4	0·8	0·8
O_2	0·5	0·1	0·1	0·0	0·2
CO	4·5	3·4	2·7	3·2	3·6
H_2	7·5	5·8	5·3	7·1	9·9
CH_4	8·3	10·5	6·1	6·8	8·4
N_2(*by diff.*)	68·2	68·1	71·9	71·3	66·0
Calorific value, Btu/cu.ft	120	148	96	115	140

The composition of surplus gas and calculated calorific values are presented in Table 6. The gas obtained with Mandamari and Raniganj coals is superior in quality and can be used as producer gas. Ghughus coal yielded a poorer gas than others.

EFFICIENCY OF THE PROCESS

Efficiencies of product recovery are presented in Table 7. They express yields obtained in the pilot plant as percentage of yields obtained in Gray-King assay. The recovery of liquid products can be increased by improvements in the condensation system.

Though it was not possible under the existing arrangements in the pilot plant to work out the complete thermal efficiency of the plant in the usual sense of the term, an attempt was made to evaluate thermal efficiency by expressing the potential heat in the products recovered as percentage on potential heat in the raw coal fed. The results (Table 8) show that generally the efficiency is between 75 and 85 per cent. The results for Kothagudem coal were based on smaller size of coal feed (1-4 in.) resulting in higher yield of recoverable semicoke. The higher efficiency in this case should be considered rather unusual. In all the other cases the size of coal feed was larger.

UTILIZATION OF PRODUCTS

The semicoke obtained was regularly sold as a domestic fuel in the cities of Hyderabad and Secunderabad. The product has proved to be a

TABLE 7—YIELDS ON CARBONIZATION IN LABORATORY AND PILOT PLANT EXPERIMENTS

	Kothagudem	Tandur	Mandamari	Ghughus	Jambad-Bowlah	Upper Kajora
Temp. of carbonization, °C.	650	650	600	650	650	650
Gray-King assay yields: (on 100 grams dry coal)						
Semicoke, g.	78·7	76·1	78·3	72·8	70·2	72·2
Tar, g.	7·14	8·9	8·3	8·1	12·1	10·2
Liquor, g.	7·5	8·7	7·9	9·1	7·5	7·5
Gas, l.	8·2	10·8	6·2	8·8	11·5	11·7
Pilot plant yields: (wt % on coal feed)						
Semicoke	73·88	64·12	71·2	62·35	64·45	63·84
Heavy tar	2·86	4·08	4·05	3·2	4·53	4·04
Light tar	2·32	3·12	2·44	3·1	4·25	4·16
Pilot plant yields expressed as per cent on Gray-King assay yields						
Semicoke	93·9	84·2	90·9	85·6	91·8	88·4
Tar	72·5	80·9	78·2	77·8	72·6	80·4

TABLE 8—THERMAL EFFICIENCY OF LOW TEMPERATURE CARBONIZATION (Potential heat in products as a percentage of Potential heat in raw coal)

	Kothagudem	Tandur	Mandamari	Ghughus	Upper Kajora	Jambad-Bowlah
Raw material						
Coal	100·0	100·0	100·0	100·0	100·0	100·0
Products						
Semicoke	79·95	61·91	69·24	65·46	60·88	61·76
Heavy tar	4·60	6·72	7·10	5·69	6·18	6·52
Light tar	3·85	5·19	4·04	5·52	6·20	6·13
Excess gas	1·95	1·22	2·87	1·83	4·23	3·39
Total	90·35	75·04	83·25	78·50	77·49	77·80
Unaccountables and losses (by differences)	9·65	24·96	16·75	21·50	22·51	22·20

successful competitor to charcoal. Recent pilot plant studies conducted at the National Metallurgical Laboratory, Jamshedpur, have shown that semicoke from Kothagudem coal is quite satisfactory as fuel for production of pig iron in a low shaft furnace.

Laboratory and pilot plant trials have shown that satisfactory types of road binders can be prepared from l.t. heavy tar. The test patches prepared by the Central Road Research Institute in India and by Messrs Lurgi Gesellschaft für Warmetechnik in Germany have proved very satisfactory.

Studies on the heavy and light tars and aqueous liquor have shown their suitability for use in the economic production of (1) conventional products such as creosote oil for timber preservation, disinfectant creosotes, fuel oil, etc. and (2) chemicals and other more valuable products such as phenol, cresols, xylenols, high boiling tar acids, liquid fuels, electrode materials, etc. These aspects will be covered in detail in subsequent communications.

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The Production of Lump Coke by Binderless Briquetting in Ring Roll Press and Subsequent Carbonization in Lurgi Internally Heated Carbonizer

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The lump coke process for the production of lumpy hard and abrasion-proof coke from brown coal is described. It involves drying the lignite in flash drying units, briquetting in ring roll presses and carbonizing the briquettes in internally heated Lurgi carbonizers. The coke can be used as domestic fuel, as raw material for gasification and for various metallurgical purposes. The process can also be applied to more matured brown coals and low rank bituminous coals by suitable modifications in predrying and crushing units.

DEVELOPMENT AND GENERAL ASPECTS OF THE LUMP COKE PRODUCTION

In the course of the development of low temperature carbonization (l.t.c.) industry which took place towards the later part of the last century, two principal objects of this coal upgrading process have become predominant.

1. Recovery of the liquid hydrocarbons as tar, middle oil and light spirit, which are subsequently distilled and refined or hydrogenated for marketing. The carbonization gas and char, which is usually of small size, are byproducts.

2. Production of high-grade, lumpy and nonfriable smokeless fuel which, owing to its reactivity can also be used as reducing agent. The carbonization gas and liquid hydrocarbons are in this case valuable by-products.

The first scheme requires coals of a high tar content, not less than 12 per cent (on dry basis); when the principal product is to be lump coke, the superior quality of the coke ensures commercial success of the carbonization process, even with coal is of a low tar content, provided the coke produced is lumpy and strong enough.

Whilst the physical properties of raw bituminous coal make it possible to produce lumpy char, the carbonization of lignite gives, in most cases, only small sized char useful only for less important purposes, for example as boiler fuel. This applies all the more to the high moisture younger brown coals which are found extensively under a thin over burden, and therefore can be mined cheaply by opencast working. These coals with their moisture content going sometimes up to 60 per cent are, prior to carbonization, suitably dried in tubular driers and briquetted in extrusion presses without any binding material. The briquettes are then fed into the carbonizer.

Based on this method and using the highly efficient Lurgi internally heated process numerous large-scale l.t.c. plants with a daily capacity of 6,000 to 12,000 tons of brown coal were established from 1935 onwards mostly in Central Germany; these plants were primarily charged with brown coal rich in tar (about 15 per cent on dry basis). The principal object of these plants was the production of tar which was converted into motor fuel by hydrogenation. The char produced in these works amounting to about 50 per cent of the briquetted lignite was in most cases only a by-product which along with the carbonization gas was used as fuel, in the power stations attached to these plants. A portion of the char was also used in Winkler gas producers for water gas generation. No particular emphasis was therefore laid on the quality of the briquettes and the coke produced from them at that time.

However, to improve the economics of l.t.c. and to open new markets for char, attempts were made to improve the quality of the char considerably, above all its shape, size and mechanical strength.

In contrast to the bitumen of certain types of bituminous coal which on being heated, has a caking and strengthening effect on the devolatilized residue by agglutinating the coke particles during carbonization, the bitumen of lignite has no such property at all[1]. In contrast to the metallurgical coke produced in normal coke-oven plants which is characterized by a molten structure, the individual particles of the char from lignite are held together only by Van der Waal's cohesive forces[2]. It is essential for the strength of those briquettes and of the char that the maximum possible aggregate of those cohesive forces are called into play. This is accomplished by crushing the coal to a very fine particle size and by the production of briquetting powder which should be as homogeneous as possible, with regard to its total moisture content, size range, as well as the moisture content in the individual size fractions.

The strength of the coke, moreover, depends on the total volatile matter content in the briquettes. It is therefore preferable to use lignite low in bitumen for the lump coke production, and to produce briquettes of the lowest possible moisture content, to reduce the shrinkage caused by drying and carbonization and the resultant cracks to a minimum.

PROCESS FOR LUMP COKE PRODUCTION

Based on these considerations Lurgi Gesellschaft für Wärmetechnik m.b.H. developed in the early thirties the Lurgi-Krupp lump coke process, characterized by the following process stages:

1. Drying the freshly mined lignite in the so-called flash drying unit, where a powdery material with about 50 per cent of particles less than 60 microns, with a low moisture content of 8-10 per cent and a narrow moisture range in the individual size fractions (2 per cent) is produced.
2. Briquetting in ring roll presses under a high pressure of 2000 kgs./sq. cm.
3. Carbonizing these briquettes in Lurgi internally heated carbonizers.

The three separate stages are operated as follows:

Flash Drying and Pulverization. In the flash drying unit the raw coal crushed in a wet preparation plant to sizes between 0 and 6 mm., or preferably 0 and 4 mm. with a moisture content of 50 to 60 per cent is dried in suspension, by means of hot flue gases in uniflow to a moisture content suitable for the subsequent briquetting (Fig. 1).

For this purpose the prepared raw coal is fed by means of a rotary table into the hot flue gases at a temperature of about 800-1000°C. generated in a special drying oven. The sudden heating of the coal by hot gases results in explosive vaporization of moisture so as to burst and shatter the particles. The coal and flue gases, now at 360-400°C. pass through a milling fan in which coal is further dried and pulverized, the gas temperature falling to 120-150°C. The coal is crushed to powder within a second and the moisture content is reduced to 6-10 per cent. The material so produced is much finer than lignite dried in tubular driers. About 50 per cent of the powder produced is less than 60 microns size. The milling fan conveys the gas laden with coal dust to the dust separation system consisting of a mechanical dust separator and an electrostatic precipitator for separation of fines. The flue gases freed from coal dust, but carrying the steam generated in drying, are discharged to the atmosphere. A certain portion of the flue gas is recycled to the oven and used to regulate the drying temperature.

The dried lignite is cooled on its way to a storage hopper feeding the

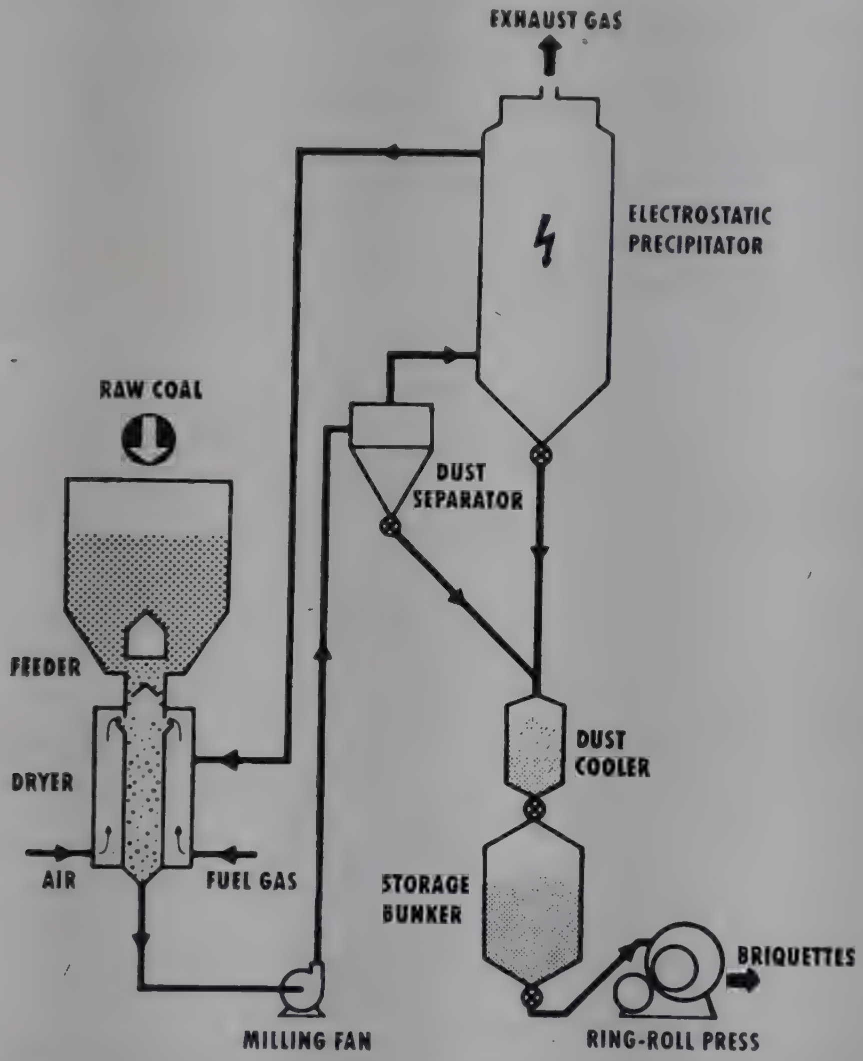
EXHAUST GAS
ELECTROSTATIC PRECIPITATOR
RAW COAL
DUST SEPARATOR
FEEDER
DRYER
AIR
FUEL GAS
DUST COOLER
STORAGE BUNKER
BRIQUETTES
MILLING FAN
RING-ROLL PRESS

FIG. 1—LURGI FLASH-DRYING, PULVERIZING AND RING ROLL BRIQUETTING PLANT FOR BROWN COAL

briquetting machine. During cooling, residual water vapour is removed and the temperature is adjusted to the desired degree for briquetting, the residual moisture being uniformly distributed among the various particle sizes of the coal.

As the gas used for heating the fuel is virtually oxygen-free, there are no losses due to oxidation, and a high degree of safety in operation is assured.

In Fig. 2 the fineness of flash-dried lignite is compared with normal dried lignite produced in steam-heated tubular driers, and with very fine lignite powder produced in steam-heated tubular driers and after treated by additional drying and crushing of coarse particles to below 1 mm. This graph shows clearly that flash drying results in very fine and uniform material suitable for producing maximum cohesive forces when briquetted under high load.

The Ring Roll Briquetting Press. The ring roll press (Fig. 3) initially used had been developed in co-operation with Krupp-Gruson Works at Magdeburg. It consists of a ring supported on two rollers which

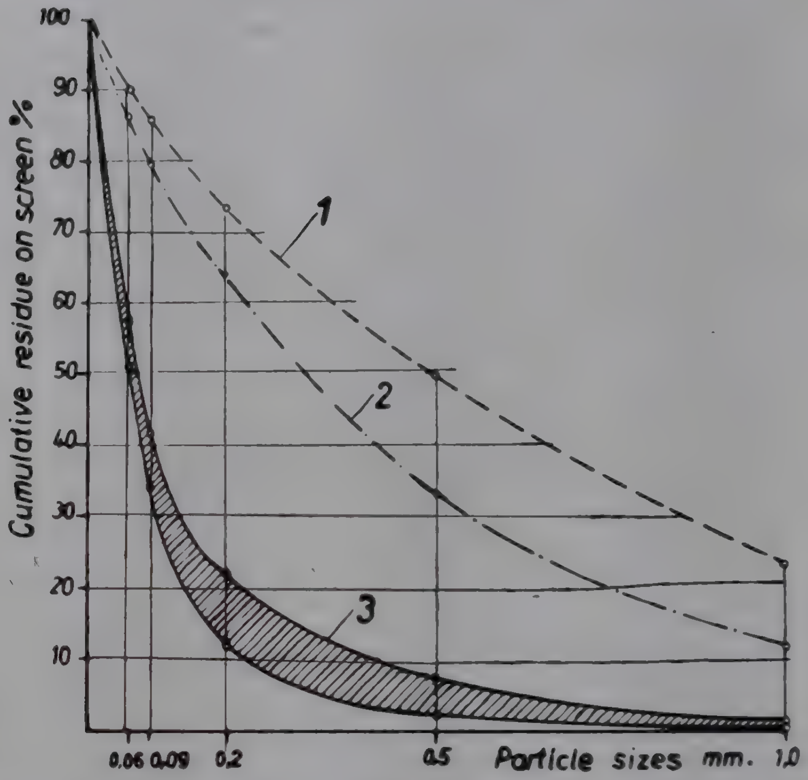

FIG. 2—SIZE FRACTIONS OF LIGNITE BRIQUETTING POWDER PRODUCED BY VARIOUS DRYING METHODS: (1) Normal steam-dried lignite (indirect drying); (2) Steam-dried lignite after treated by additional drying and crushing of coarse particles to below 1 mm.; (3) Size range of flash-dried lignite for various types of lignite

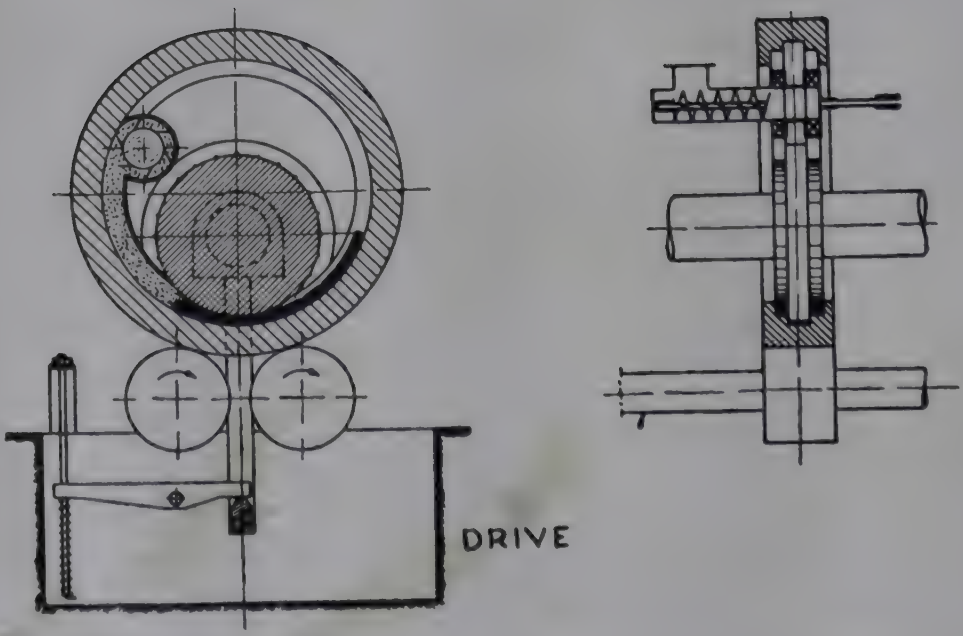

FIG. 3—LURGI-KRUPP RING ROLL PRESS (ACCORDING TO HERGLOTZ)

act at the same time as driving pulleys. A rotating disc is eccentrically mounted inside the ring.

In contrast to the press developed by Apfelbeck and that developed by Maschinenfabrik Buckau, the press made by Krupp was with 2 grooves. It consisted of a ring of 3160 mm. diam. and 55 mm. width which had two briquetting grooves. The rotation of the ring was accomplished by forces due to friction emanating from the two driving pulleys which at the same time act as supporting rollers for the ring. The two driving pulleys are driven by a motor via a spur gear and a transmission gear. The rotating disc is moved whilst the briquettes are formed. The speed of the driving motor was variable (Leonard set or commutator motor). The pre-load

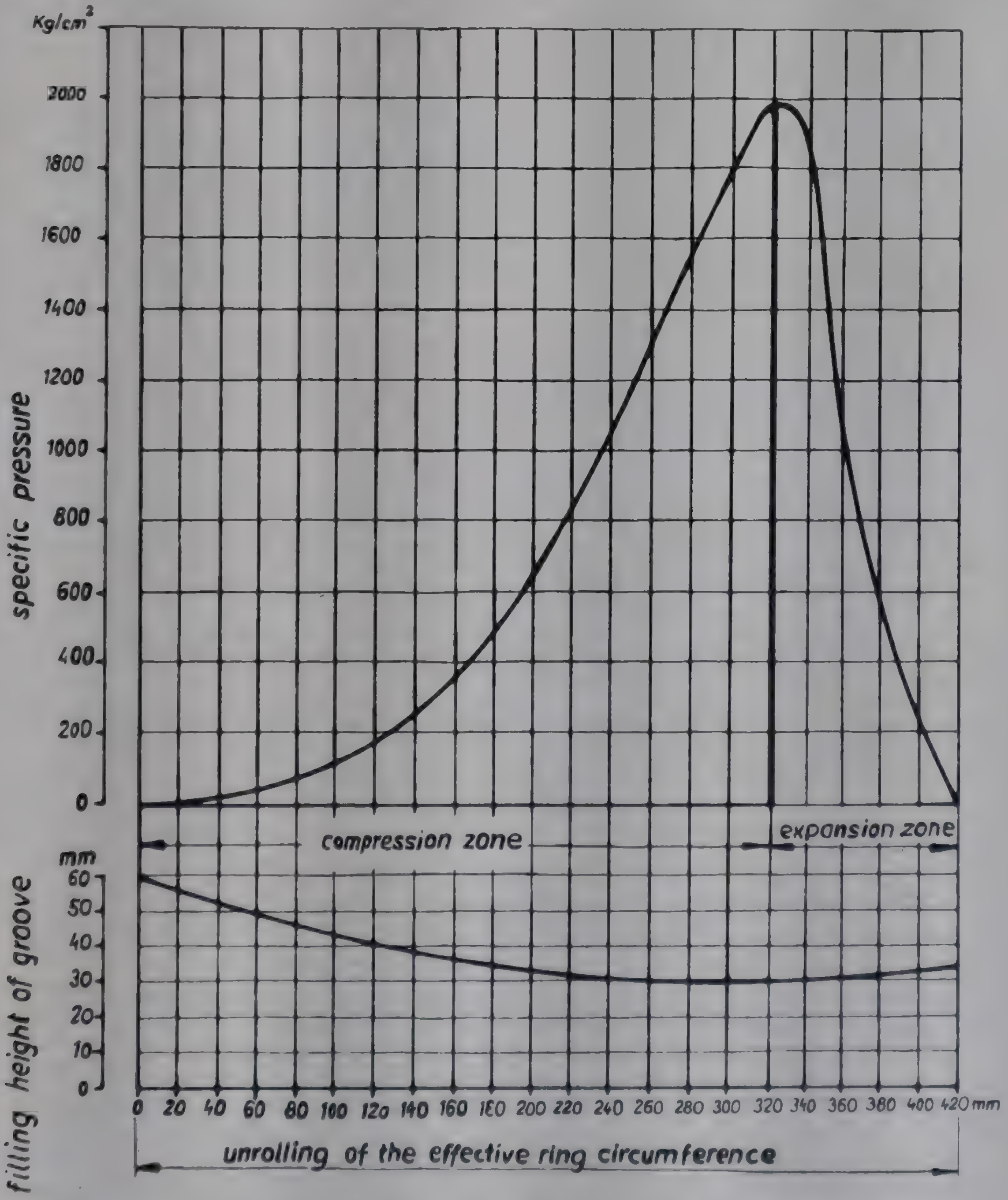

Fig. 4—Pressure vs ring travel of the single roll ring roll press

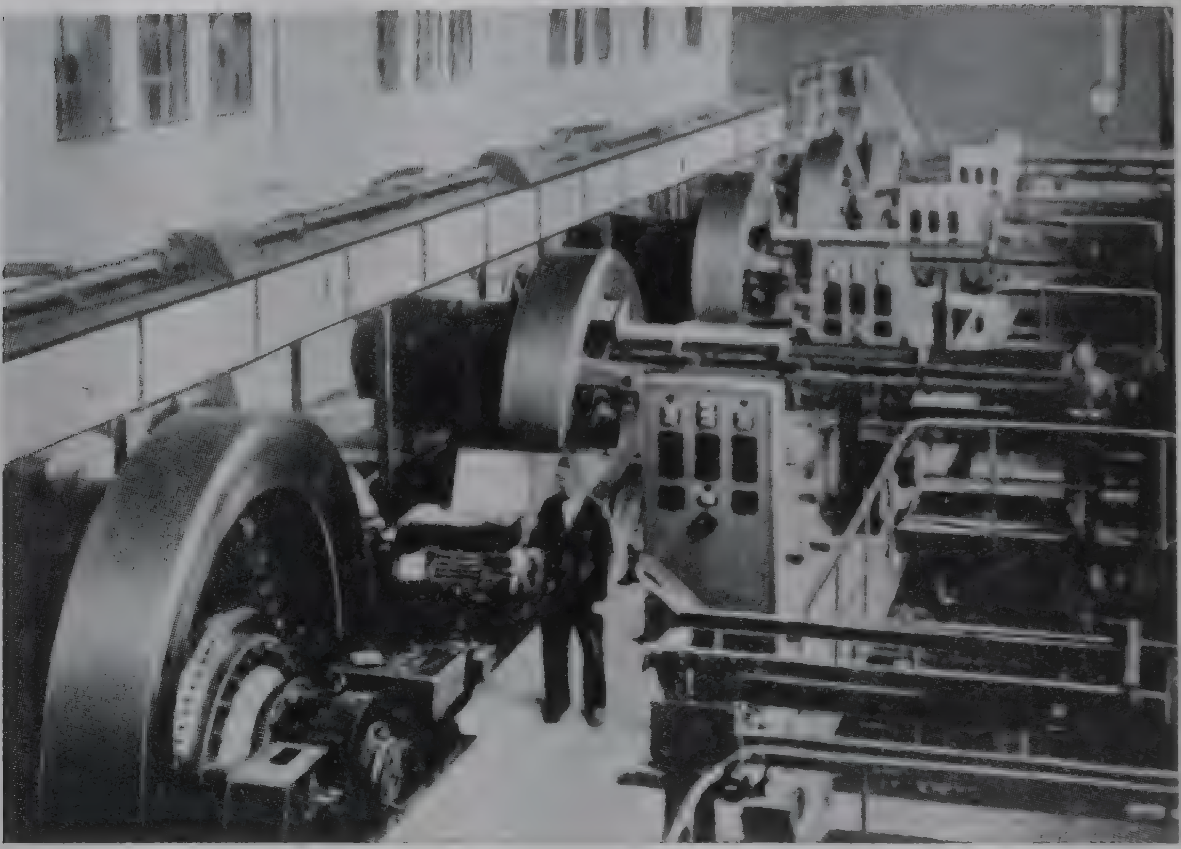

Fig. 5—Press hall of a ring roll briquetting plant in Central Germany

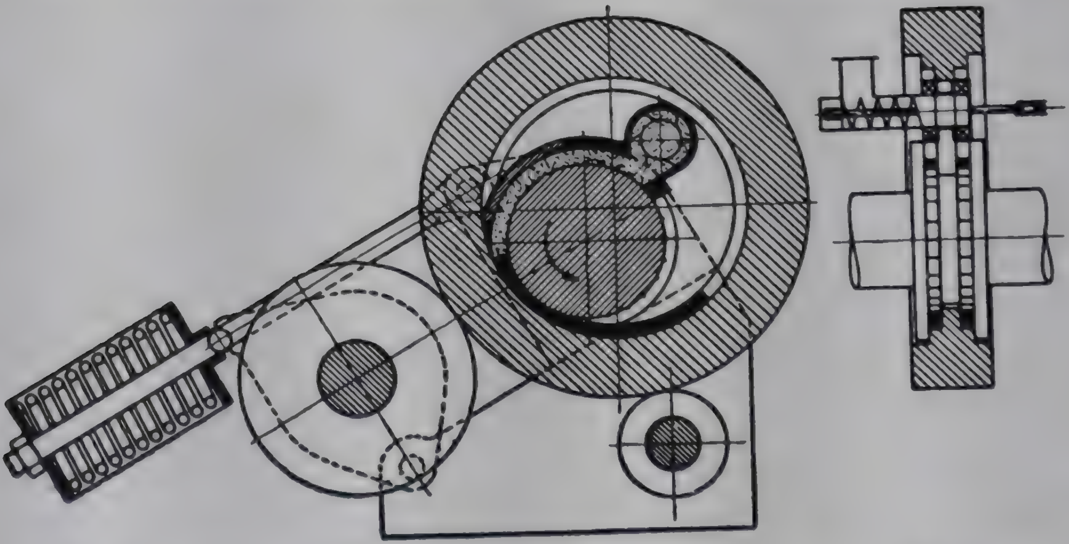

Fig. 6—Lurgi Kloeckner-Humboldt ring roll press (According to Kohler)

was given by springs via rotary disc. The powder was fed into the moulding grooves by means of worms with a variable speed range and a feeding blower. The feeding blower was operated with coal in excess, so that the powder entered the filling ducts of the press under a slight overpressure, i.e. in a somewhat precompressed state. Excess powder was returned to the system by means of a return worm and a drag-chain conveyor. The worm system and feeding blower are likewise driven by an adjustable motor.

Due to rotation of the ring, the powder is carried through the filling duct which narrows more and more into the pressing zone, where it is moulded into briquettes by the action of the rotary disc under tension. The rotary disc is likewise rotated by the forces due to friction so that a continuous operation is established. The narrow angle formed between the disc and ring assures exertion of high pressure on the material fed to the moulds. The streams of readily moulded briquettes are carried in the grooves of the ring on the discharge side as far as the breaking device, where they are broken into single briquettes of suitable length and then conveyed to the carbonization plant by the belt conveyor.

The Krupp press has been constructed for a total pressure of 400 tons and permits the application of a maximum pressure of 2000 kg./sq. cm. in the pressing zone. The pressing process consists in a pressure wave gliding over the material to be pressed but once, whereby the pressure exerted on the material to be briquetted increases to a maximum and subsequently decreases rapidly, as shown in Fig. 4.

Twenty-six presses of this type had been installed at various lump coke plants in Central Germany, each with a daily capacity of up to 300 tons of briquettes. The Fig. 5 gives a view of the press hall of a lump coke plant erected in Central Germany in 1937.

Based on experience in the operation of the old press, a new one was developed after the war with a view to improve, above all, the drive, to reduce the weight, and to directly transmit the forces by a back-pressure roller. This new press designed by Lurgi in co-operation with Kloeckner-Humboldt-Deutz AG is termed 'one roll ring roll press' (Fig. 6). This press is characterized by its slanting construction. The rotating disc is driven, whereas the ring is moved by briquettes moulded between the rotating disc and the ring. The ring rests on supporting roller, and pressure is directly transmitted to a pressure roller. The initial tension is also effected in this case by laminated springs and the pressure roller. The coal is fed into the moulding grooves by means of worms with a variable speed control or a feeding blower.

Owing to the direct transmission of briquetting forces from the rotating disc to the pressure roller, the weight of the press has been considerably reduced and is only 77 tons compared to 125 tons of the Krupp-Lurgi press. The new press therefore also weighs less than extrusion presses of the same capacity, as may be seen from Table 1.

The normal industrial type of the newly developed Lurgi ring roll press has a capacity of about 300-360 tons per day (Fig. 7).

A smaller type has also been developed with a daily capacity of about 100 tons of brown coal briquettes. In this type of press other materials such as calcium hydroxide and iron sponge pellets have been successfully briquetted. A commercial plant for the briquetting of calcium hydroxide is now under construction (Fig. 8).

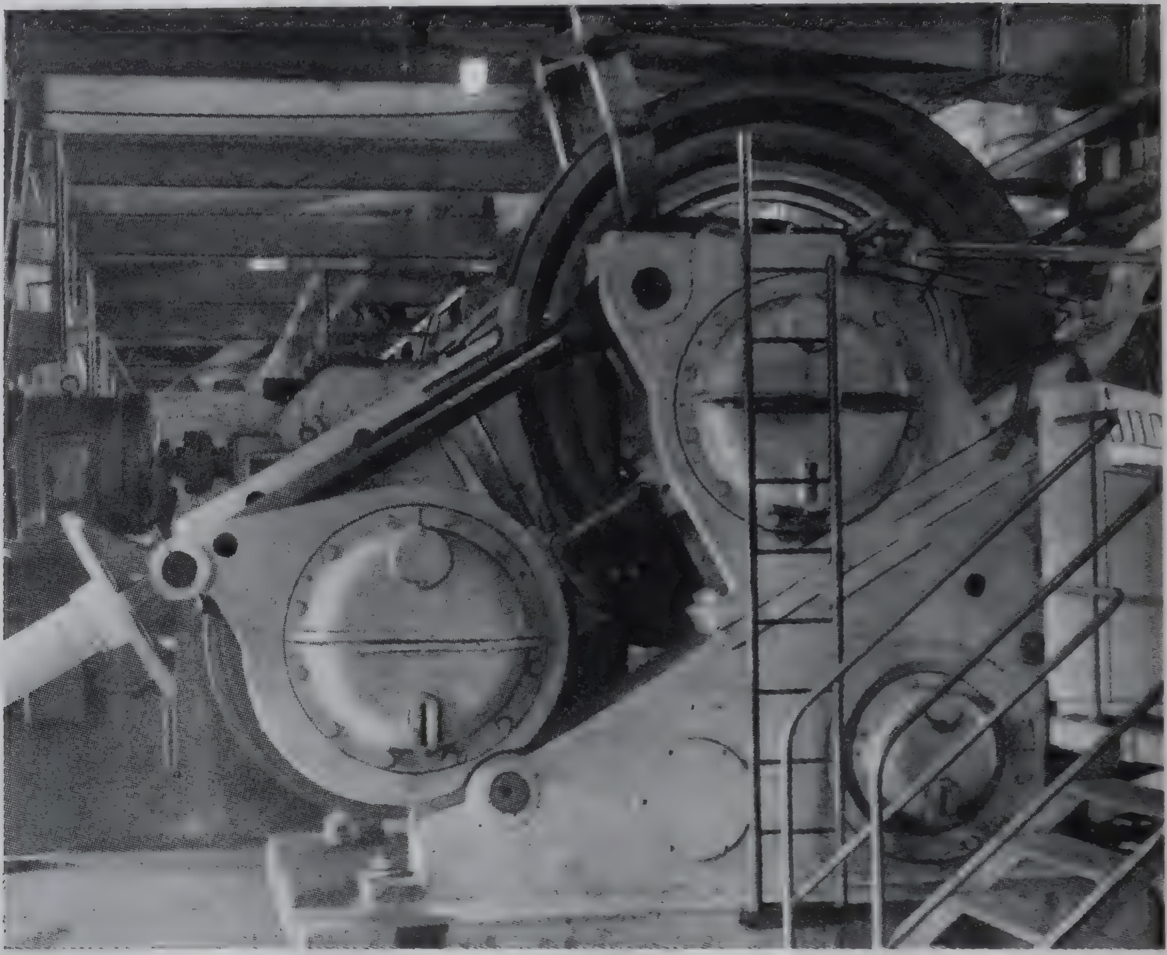

Fig. 7—Lurgi ring roll briquetting press (Capacity: 330 tons of briquettes per day)

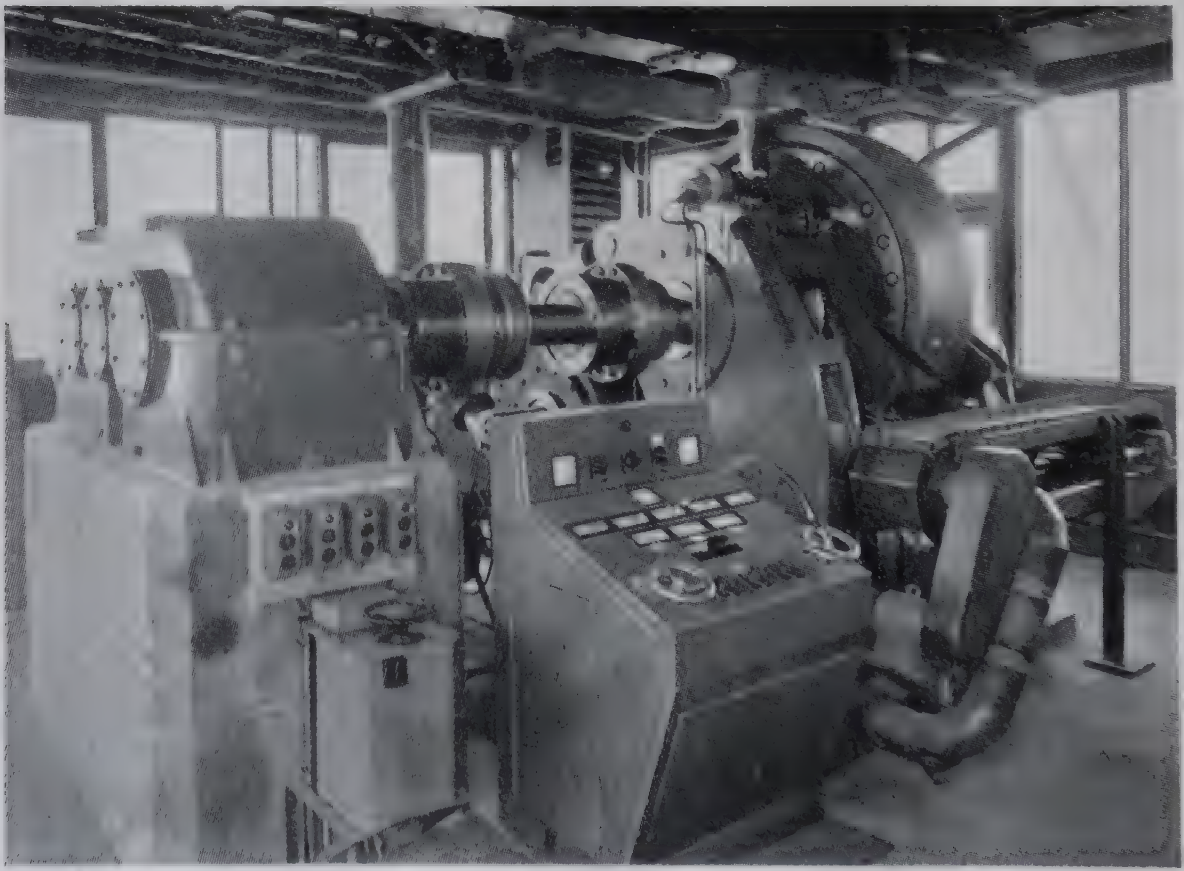

Fig. 8—Lurgi ring roll briquetting press (Capacity: 100 tons of briquettes per day)

TABLE 1—WEIGHT AND CAPACITY OF VARIOUS PRESSES

TYPE OF PRESS	WEIGHT OF PRESS, tons	DAILY CAPACITY, tons	WEIGHT OF PRESS PER TON OF DAILY BRIQUETTING CAPACITY
One-plunger press	54	70	0·77
Two-plunger press	63	140	0·45
Three-plunger press	65	210	0·31
Four-plunger press	120	280	0·43
R. W. press (Krupp-Lurgi)	125	300	0·41
R. W. press (Lurgi-Humboldt)	77	330	0·32

The power requirements per ton of briquettes are approx. 12 kwh/ton, about 40 per cent of the power required by the extrusion press. The briquettes produced on the ring roll press are rhomb-shaped. In case of the large press briquettes are of 70×57×35 mm. size weighing about 175 g. Those from the small press are of 50×35×28 mm. size weighing approx. 65 g.

The moulds of the ring roll presses are made of chrome alloy steel. Steel of medium wear resistance with an intrinsic fatigue resistance of about 80 kg./sq. cm. which can be increased by heat treatment to approx. 105 kg./sq. cm. is sufficient in many cases. For moulds of a higher wear resistance steels used are of the following approximate composition: C=2 %; Si=0·25 %; Mn=0·8 %; Cr=2·1 %. Such type of steel is heat treatable up to a maximum of 170 kg./sq. cm. However, the heat treatment is normally carried only up to a resistance of 130 kg./sq. cm. These moulds are capable of handling the following quantities of briquettes before they need the first regrinding: Ring, 70,000 tons; Disc, 30,000 tons, because of the higher speed of the rotating disc.

It can be calculated from these capacities of the moulds (ascertained in practical operation with Rheinish brown coal) that depending on the nature of the coal up to 2 million tons of briquettes can be produced in these moulds before they are completely worn out due to repeated regrinding. These results also show that the costs of the moulds amount only to about 60 per cent of those for extrusion presses.

The briquettes produced in the ring roll press are of a particularly high strength and homogeneity. The Central German plants reached daily average values in the briquette of 150 kg./sq. cm. and of densities of 1·2 even with coals rich in tar.

Low Temperature Carbonization in Internally-heated Carbonizers. The briquettes are then conveyed to the Lurgi internally-heated

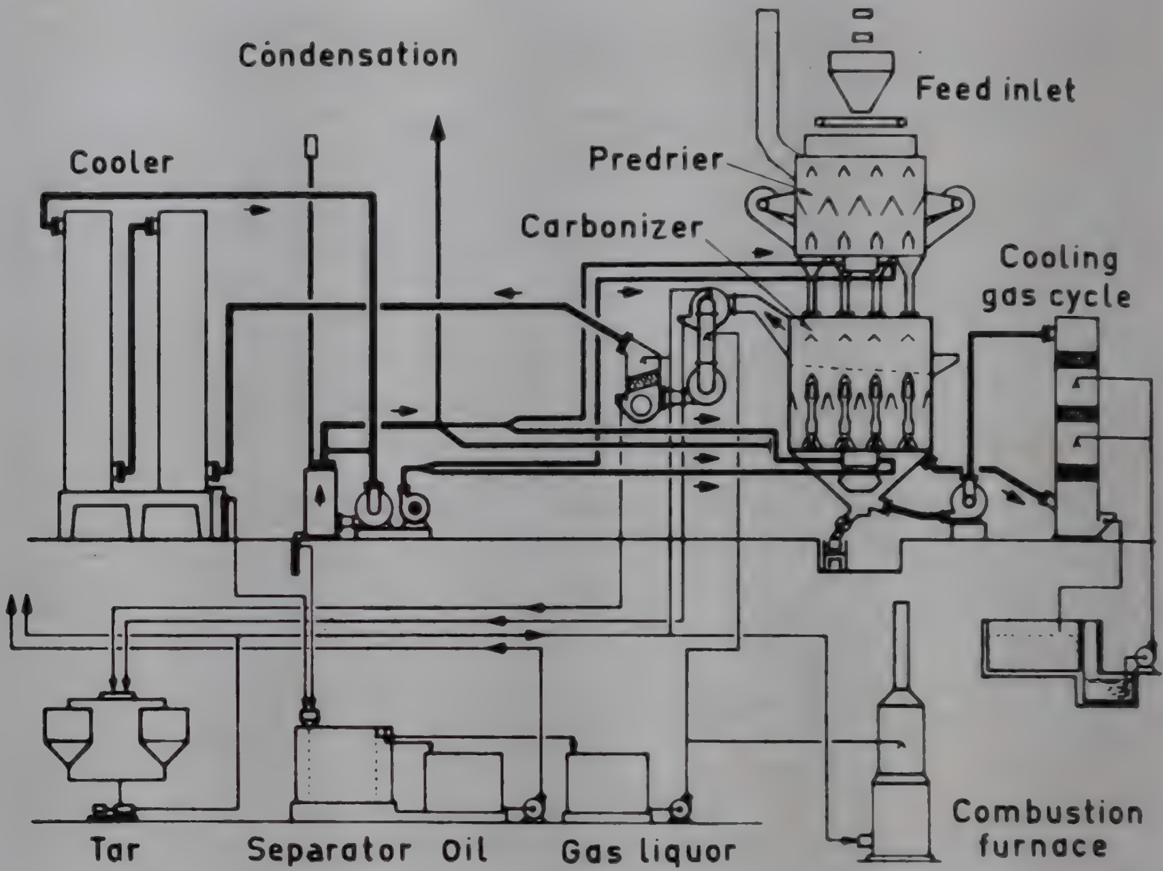
Condensation
Feed inlet
Cooler
Predrier
Carbonizer
Cooling gas cycle
Tar
Separator
Oil
Gas liquor
Combustion furnace

Fig. 9—Flowsheet of a modern plant with cooling gas recycle system

Fig. 10—General view of a low temperature carbonization plant with briquetting factory

carbonizer, and are distributed by means of feeding hoppers to two carbonizer shafts of the industrial unit and pass through the carbonizer from top to bottom, the speed being adjusted by the coke extractor operated by an infinitely variable drive. The briquettes charged with a moisture content of 8-10 per cent are at first carefully dried in the predrier to 0-1 per cent moisture content. If the briquettes are highly hygroscopic, a preliminary additional stage may be provided in which the briquettes are slowly heated with gases of a low dew point and a relatively low temperature of about 100-150°C., without causing any deposition of moisture on the surface of the briquettes.

The dried briquettes entering the carbonizer shaft through the connecting ducts are carbonized in the presence of recycled 'Spuelgas', which is heated in a combustion chamber and passes directly through the briquette bed. The carbonization gas temperature can be maintained between 600 and 900°C. by means of the heating contrivance of the carbonizer burner to produce char of different volatile matter contents (Fig. 9).

The briquettes then enter the coke cooling zone where they are cooled either by the cooling gas from the carbonization gas recycle system or by a separate cooling gas recycle system so that they leave the carbonizer at a temperature of 80-100°C. The separate cooling gas recycle system has a very intensive cooling effect and makes at the same time the removal of light spirit from the carbonization gas recycle system unnecessary, which is of particular advantage if the briquettes are of a low tar content (Fig. 9).

The liquid products are subjected to fractional condensation in the usual way, and the thick tar, electrostatic precipitator tar, the middle oil, light oil and gas liquor are recovered. The gas liquor can be purified in a Phenosolvan plant and the monohydric and polyhydric phenols extracted. The gas liquor with a residual phenol content of about 10 mg./lit. which can be decomposed in a biological purification plant to such a degree as to be drained off into rivers[5].

Tar and middle oil can be used as fuel oil. If the plants are of a sufficient size, tar and middle oil in combination with light oil can also be converted into motor fuels by hydrogenation. Monohydric phenols can moreover be recovered from the lighter middle oil fractions by means of the Phenoraffin process, which improves the economy of the overall plant.

RESULTS OBTAINED WITH PLANTS MAKING LUMP COKE

Based on the process described above twenty-six predrier and carbonizer units with capacities ranging from 1,500 to 5,000 metric tons of raw brown coal per day were installed in Central Germany and successfully operated in Central Germany until they were dismantled shortly after the war in 1945. One of these plants is shown in Fig. 11.

The coke produced in these plants was characterized by its lumpiness. During the after-treatment of the coke discharged from the carbonizer which, in most instances, consisted in the quenching of coke on vibrating conveyors, the coke breeze of less than 10 mm. size amounted only to about 5-10 per cent, depending on the tar content of the coal used. The coke was

Fig. 11—Lump coke plant with ring roll briquetting and carbonization units with a daily capacity of 6500 metric tons of lignite

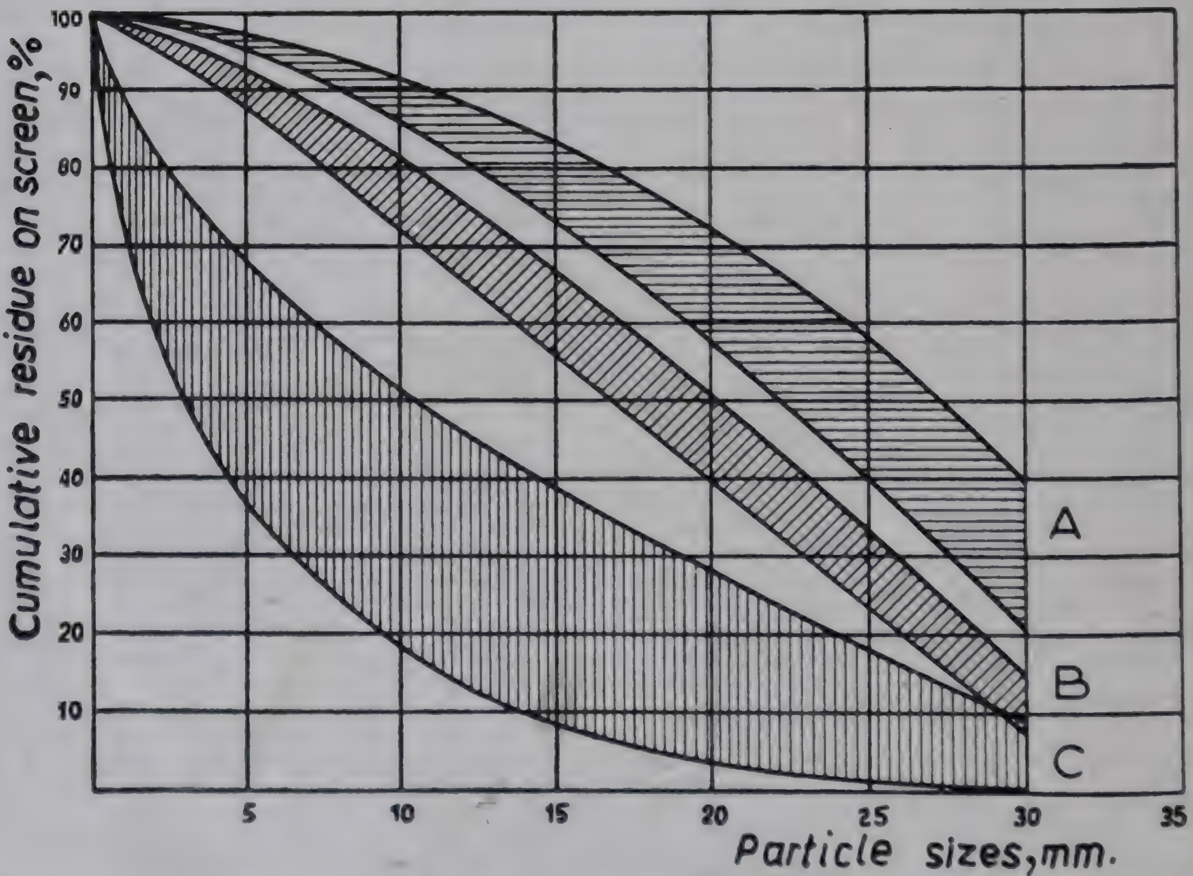

Fig. 12—Size grading of various types of semicoke made from lignite: (A) Range of particle size for lump coke made from ring roll briquettes (B) Range of particle size for semicoke made from steam-dried extrusion press briquettes (C) Range of particle size for semicoke made from flash-dried extrusion press briquettes

TABLE 2—CHARACTERISTIC DATA OF LUMP COKE PRODUCED FROM THE CENTRAL GERMAN BROWN COAL

Tar content in the raw coal (dry basis), %	18·7	13·0	14·0
Carbonizer throughput, tons/day	305	310	310
Size analysis of the lump coke			
Above 30 mm., wt %	30·2	34·0	44·0
30—10 mm., wt %	65·2	61·0	53·0
< 10 mm., wt %	4·6	5·0	3·0
Gross calorific value, kcal./kg.	5650	5910	5830

then classified for marketing into lumps with more than 30 mm. long edges and less than 30 mm. and sold as 'Brikozit'.

As the lump coke has a fine porous structure it absorbs less water than granular coke produced from the same type of lignite and has therefore a higher calorific value. It can, moreover, be better stored and even if stored for several months has only small losses due to abrasion.

Characteristic data[1] of the coke produced are indicated in Table 2.

The heat and power consumption by the lump coke plant is comparatively moderate. The power consumption by the various units per ton of briquettes is given below:

(a)	flash drying and ring roll press briquetting plant	approx. 33 kwh
(b)	carbonization plant including auxiliary plants	approx. 18 kwh
(c)	the heat required for the predrying of the coal	approx. 760 kcal./kg. of water
(d)	average production of briquettes in ring roll press per worker per shift	10·5 tons

Depending on the moisture content in the coal and on the operating conditions of the carbonization plant, 40-80 per cent of the heat required for predrying can be met by surplus gas available from the carbonization plant; the quantity of gas required in excess of this surplus gas amounts to approx. 210-250 Nm^3/ton with a calorific value of about 1800-1950 kcal./$Nm.^3$ The additional heat required for drying the coal can be provided by a raw coal firing system or by firing tar or oil.

Various tests show that not only the briquetting method, but also the special drying method has a favourable effect on the properties of the char, as the spontaneous heating has a favourable influence upon the properties of the lignite powder and reduces the hygroscopicity of the briquettes. The flue gas used for the predrying can be employed in a simple manner for inertizing the conveyors and the so-called dust handling plant, so that a spontaneous ignition within the conveying equipment and predrying plants is virtually eliminated.

COMPARISON WITH OTHER PROCESSES AND PRODUCTS

Fig. 12 gives the size grading of various types of semicoke made from lignite by different processes. As mentioned earlier, carbonization of briquettes produced from normal steam-dried lignite on extrusion presses results in a finely granular friable char with only 20 to 50 per cent particles above 10 mm. These are the characteristics of the char produced in normal carbonization plants in Central Germany, erected for the production of tar for hydrogenation. The curve in the middle shows the characteristics of a special sort of lump coke which is produced from a lignite relatively low in tar (12 per cent on dry basis) in Offleben (Western Germany) in this case the flash-dried lignite of medium fineness is briquetted in extrusion presses. Drying, briquetting and carbonization have been very carefully developed during the past 15 years to achieve lumpy char product which makes the plant economical[5]. The upper curve shows the size grading of lump coke produced by the carbonization of ring-roll briquettes, made from flash-dried lignite (14-18 per cent tar on dry basis) in the Lurgi flash-drying system. The combination of these working methods in the lump coke plants in Central Germany resulted in a char of high density and strength with 85 to 92 per cent particles above 10 mm. under normal operating conditions[1].

Production of lump coke by carbonization of briquettes made from finest dried coal has also been tried by other methods. Very fine briquetting material of a low moisture content was produced by drying coal in tubular driers, and by subsequent drying and grinding the coarse particles to sizes below 1 mm. The briquettes were then coked in externally-heated ovens[2]. However, this process which gives the so-called BHT coke* is relatively expensive, and the energy requirements to briquette this fine coal in an extrusion press are about three times those in the ring-roll press[4].

The operation of externally-heated ovens is more complicated and needs more maintenance than the internally-heated carbonizers and the investment costs are also higher.

The dense texture of the briquettes made in ring-roll presses and of the coke produced from them makes it particularly suitable for metallurgical processes. Coke from briquettes made in ring-roll presses was already successfully used during the thirties in electric furnaces for the production of carbide and phosphorus, and its lumpiness, crushing strength and resistance to abrasion are not inferior to those of the BHT coke. By suitably modifying the operating conditions of the internally-heated carbonizers and by the application of higher 'Spuelgas' temperatures, the requirements of the metallurgical industry can be met.

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* Coke produced in externally-heated carbonizers at high temperatures.

Tests on Neyveli lignite performed on a laboratory and semi-technical scale have shown that briquetting under high pressure of the flash-dried material gives briquettes with a crushing strength of 300 kg./sq. cm. and semicoke of 210 kg./sq. cm. crushing strength, whereas the material briquetted in extrusion presses (0-2 mm.) at 1000 kg./sq. cm. gives only about half this value. The tests have shown that this method[6] is highly suited for this type of coal with a low tar content and gives a high yield of lumpy, strong coke whose strength, resistance to abrasion and reactivity are not inferior to those of BHT coke.

The lump coke process is not only restricted to the young brown coal, but can also be applied to older brown coals and low rank bituminous coals by introducing suitable modifications in predrying and crushing units.

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DISCUSSION

Dr H. Rieschell: The paper by Mr Lange gives firstly the impression that there is only one process, using Ring Roll Press, for making lumpy coke. In Central Germany, a process using an extrusion press has been developed to make good coke. We had to use an externally heated oven since in the internally-heated oven there were difficulties due to gasification at such high temperatures.

Secondly, only the advantages of the Ring Roll Press have been mentioned. But actually difficulties are encountered in feeding the press and also due to the expansion of briquettes. The size of briquettes cannot be changed in Ring Roll presses whereas this is possible with extrusion presses. In Lauchhammer, using extrusion presses, briquettes of sizes 105 × 70 × 40 mm., weighing 300-320 g. and with a crushing strength of 240 kg./sq. cm. and a density of 1·2 g./cc. have been produced.

The figures on grain size of coke obtained from extrusion press as given by Mr Lange are not the best and may refer to coke from normal briquettes and not briquettes from fine grained lignite. The figures obtained for coke at Lauchhammer were: +45 mm., 45-55 per cent, with a maximum of 65 per cent; +30 mm. 65-75 per cent; +10 mm., 88-93 per cent. Abrasion in Micum drum was 55-65 per cent above 40 mm.

Mr P. H. Lange: It was not the intention to show that Lurgi lump coke process is the only one available for production of metallurgical coke; there will be many other processes. They, however, depend on the character of the coal.

In the development of processes for production of metallurgical coke from lignite in East Germany, the possibility of briquetting in Ring Roll presses was also taken into consideration; but at that time no Ring Roll presses were available. Further, a coal suitable for briquetting in extrusion presses was easily available and good results were obtained by the fine-grained process and briquetting in an extrusion press. Using externally heated ovens it is easy to get a low volatile matter content in coke. Use of higher temperatures in internally heated carbonizers depends on the reactivity and porosity of coal. The difficulty of gasification reactions taking place at higher temperatures in these ovens can also be overcome by having the right equilibrium among the gases passing through the carbonizer.

Regarding the size of the briquettes, at that time, and to some extent even today, metallurgical coke of bigger size has been in common use. There has recently been a tendency to use smaller coke and briquettes from moulded anthracite fines or carbonized briquettes for the smelting of iron ores. Use of smaller fuel has the advantages of a uniform fuel bed and increased capacity of the unit.

The difficulties in feeding the Ring Roll press are not only due to the type of lignite but also the arrangement of feeder. We have developed a Ring Roll press at Rodergrube for a coal having a high expansion rate. There were initial difficulties due to defects in construction but they were overcome in a few months. The press is now working satisfactorily and steadily without difficulty.

GENERAL DISCUSSION ON L.T.C.

Dr S. K. Sircar: There are tremendous possibilities in India for l.t.c. and it can be an economic success provided the aim and the main products desired are clearly defined. The selection of the l.t.c. process depends upon the purpose for which l.t.c. is adopted. In order to utilize coal fully and efficiently, it should be processed and it appears l.t.c. is necessary to avoid the use of unprocessed coal. Another aspect to be considered is the materials required in the construction of l.t.c. furnaces and whether they are easily available in India.

Dr M. R. Mandlekar: I would like to emphasise on some organizational aspects of the l.t.c. industry. It is reported that even for research work it is difficult to get regular supplies of coal. If that be so in the coal belt region, the situation is still worse particularly in areas in the Western Maharashtra which are far removed for coal fields. Transport difficulties have to be taken into account while working out the economics of the industry. Section of the right type of l.t.c. process to treat different types of coals and the proper disposal of byproducts are two other important considerations to be kept in mind. It is possible that certain processes can be successfully worked out in the laboratory but may not work out in certain areas.

Dr H. S. Rao: It is clear from the papers that the main objects of l.t.c. is to produce suitable domestic fuel. However, domestic coke alone cannot bear all the costs. While working out methods for recovery of byproducts and manufacture of specific products from l.t. tar, one has to consider the increasing competition from the petroleum industry which employs well-established processes.

Dr C. V. S. Ratnam: I wish to emphasise the point concerning the aim of l.t.c. namely. the production of domestic fuel. The need for supply of suitable domestic fuel is not keenly felt in some parts of the country whereas in other parts the problem is serious. In some places, raw materials and the need for using them may exist, whereas in other places the need for a product exists but the raw material may not be available. The establishment of l.t.c. plants has not gone forward because of other considerations such as availability of resources.

In the next few years, there may be a famine for domestic fuel and then every State will feel the necessity for l.t.c. plants just as in the case of fertilizer plants.

With regard to the raw materials for the l.t.c. industry, it would be necessary to concentrate more on the use of non-caking coals and integrate the new steel plants with l.t.c. plants using char for steel making. Even the existing steel plants are experiencing shortage of coking coals of good quality. This would be more so, with increased production of 10 million tons of steel at the end of the third five year plan.

Many processes have been tried for l.t.c. but only a few have survived. On a large scale, only the Lurgi process appears to be commercially suitable for l.t.c.

Dr K. L. Ramaswamy: I am interested in the industrial utilization of what the research institutions have achieved. In Bihar we are proposing to set up l.t.c. plants. In this connection, I wish to mention some important aspects. The first is the economics. The price of l.t.c. coke should not be compared with the price of coke as it exists today but with other fuels used for domestic purposes. In a few years all the coke produced will be directed to the steel industry. Non-caking coals alone are to be used for domestic fuel manufacture. With increased standards of living, increase in population and forest depletion, a time will come when domestic fuels should be derived from coal. The second aspect is the ash content of domestic coke which is at present very high, of the order of 50 per cent; with systematized l.t.c., a control in ash content can be maintained and the cost will be bearable by the customer. Thirdly, apart from transport difficulties, the question of availability of coal is also a problem. The research institutions should take this up with the Coal Board, Fuel Ministry and Railway Board and find out which coals will be available for l.t.c. in the near future, and then start testing these coals. A case is known when a project report was made for l.t.c. based on a certain coal and subsequently it was found that the coal was already sold out. If a co-ordinated effort in consultation with the concerned Ministries is made, the results will be better and quicker.

Dr M. G. Krishna: In this country the uneven distribution of coal reserves should be carefully considered in planning the rational utilization of coal. The economics of every industry using coal is linked with the crucial aspect.

So far as the aim of l.t.c. in India is concerned, at least for some time to come, it will be the production of domestic fuel in the form of lumps. As industrialization proceeds and technology advances, char will find use for other purposes such as power generation. There is no competition between the various forms of fuel. They are all complementary and they should be used wherever they are available and advantageous.

From the several papers submitted to this session, it is seen that a variety of raw materials such as weakly caking coals, non-caking coals, lignites, coal briquettes, etc. are subjected to l.t.c. in different countries. The choice of any particular process depends on the raw material and local conditions. As far as this country is concerned, we have only limited reserves of caking coals and we should strive to conserve these coals. L.t.c. should, therefore, be primarily based on weakly caking and non-caking coals and lignites, especially those with high ash content.

Nearly 25-30 per cent of the total coal production is in the form of dust and this proportion will be higher with increased mechanization. Disposal of the fines will certainly be a problem in the coming years. Briquetting of the fines, which is at present not being done in the country and subsequent carbonization of the briquettes will have to be seriously considered in future.

Regarding the allocation of coal for l.t.c. as referred to by Dr K. L. Ramaswamy, a high power committee is looking into this problem and the research laboratories are not in a position to do much. It is a policy matter and all that the laboratories can do is to test various coals and state which of them are suitable for l.t.c.

Dr M. S. Iyengar: The scope for l.t.c. is immense in a developing country like ours and different aspects are bound to influence the development of the industry. The immediate problem, however, is the supply of domestic fuel. We are living in a cowdung age; about 380 million tons per annum of cowdung are burnt as fuel. This should have been used as fertilizer. This has been dramatically put by N.C.A.E.R. as equivalent to burning 12 Sindris annually. On the one hand we are trying to set up fertilizer plants to increase food production and on the other we are burning cowdung. Hence a suitable fuel has to be supplied for rural areas so that cowdung can be spared for right purposes. Similarly for urban areas semicoke has to be supplied to stop the use of charcoal.

The Central Fuel Research Institute has developed a process using chain grate stroker without byproduct recovery. This is a compact unit. As an immediate step to stop use of cowdung as fuel, such units can be located in rural areas. In big cities modern plants with byproducts recovery can be erected as the industry advances.

There is one more aspect. There is an imbalance in the production of liquid fuels in the country. While gasoline and fuel oil are produced in surplus, there is a shortage of diesel oil. By hydrofining the tar and converting to diesel oil, this imbalance can be partly met.

Dr M. G. Krishna: One aspect mentioned by Dr Iyengar is the l.t.c. of coal of chain grate stoker without byproduct recovery. Whether byproduct plants should be included or not and whether tar should be burnt or converted to diesel oil and other products are matters of policy and are governed mostly by economics.

Shri B. Sethuram: During the washing of coal, 60 per cent clean coal is obtained. The disposal of remaining 40 per cent in the form of middlings and rejects poses a problem to the washery owners. This problem is going to be felt more and more in the coming years with the setting up of more washeries. Heaps of rejects will start accumulating at the washeries. Indian coals are known to have high middlings and there are not many boilers to use these middlings. If these can be subjected to low temperature carbonization, the domestic fuel problem will be solved to a certain extent and at the same time provides for the disposal of byproducts of washeries.

Shri P. H. Lange: There is not only the possibility of carbonization of the washery middlings but also of burning in a fluidized bed for power and steam generation. The Lurgis have developed a method to burn oil shale fines to produce power. Similar process is possible for coals with 10-15 per cent fixed carbon.

Shri R. R. Fernandez: Regarding the utilization of coal or charcoal breeze briquetting it using dung, tamarind seed and similar other materials as binder has been practised commercially in Bombay. The products are as cheap as charcoal.

Dr S. K. Sircar: Shri Sethuram has posed the problem of disposal of middlings and rejects. Middlings can be burnt in boilers. The problem is whether coal should be used as such or in finished form. There is provision in the Durgapur plant for burning middlings in the power station. The middlings and rejects are produced at a rate of 300 tons/day. If the middlings or rejects are carbonized at low temperatures, the product will have better burning properties. The ash content will not be serious as it is difficult to get coke with ash content less than 40-50 per cent in Calcutta. Strangely no paper on l.t.c. of middlings has been presented. This aspect may be investigated by the research institutes.

Dr H. H. Koppers (written contribution): When charging an Indian coal with 20-22 per cent ash (dry basis), the coke produced contains about 28-31 per cent ash. If middlings of suitable size were to be subjected to l.t.c. with an ash content of about 32 per cent, the coke would have about an ash of 40 per cent or more. The production of a coke of this type cannot be considered economical. Therefore, I will not recommend the l.t.c. of middlings. It might be possible to consider gasification of middlings.

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